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Quantifying the Effect of Pedestrian Control Devices on Pedestrian Safety

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Quantifying the Effect of Pedestrian Control Devices on Pedestrian Safety

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2018

Acknowledgments

I would like to express my sincerest gratitude to all of the people that have been supportive of my quest for learning and development. Mami, Papi, Cathy, and Martin have always offered encouragement, especially at times when I needed them most.

Mami, even when I was a little girl you celebrated my curiousity. When I would ask a million questions about anything and everything, you never simply told me, "I don't know." You always said, "Buena pregunta, hay que investigar eso."

Cathy, thank you loving me for who I am and for (eventually) totally appreciating the phrase, "Where's your research?" as much as I do.

Papi, you've been my rock from day one in school always pushing me to become better and helping me envision a wonderful future.

Martin, thank you for always being there by my side and believing in me when I forgot to believe in myself, and for helping me with everything.

I'm especially indebted to Dr. Randy Machemehl who has been a wonderful mentor, teacher, and guide. He's been kind, supportive, and taught me so many things both within and outside of transportation engineering. I also want to thank all of my instructors for making graduate school fascinating and rewarding, especially Dr. Zhanmin Zhang and Dr. Matt Hersh. Lastly, I would like to acknowledge Dr. Wonsuck Kim, who initially sparked my love for conducting research when I was completing my undergraduate degree. Without him, I wouldn't have fallen onto this wonderful path that I'm so grateful to be on.

Abstract

Quantifying the Effect of Pedestrian Control Devices on Pedestrian Safety

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The University of Texas at Austin, 2018

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There are many interventions that can reduce pedestrian crashes, including clarifying the indications transmitted to the travelers in the traffic network via the built environment. By design, the built environment aims to make who has the right-of-way very clear by presenting expected, easy-to-interpret indications. Some environments are much clearer than others, for example a marked crosswalk versus an unmarked crosswalk and can influence yielding behavior and fatal crash probability. This thesis presents the findings on driver yielding toward pedestrians at various crossing treatments and on fatal pedestrian crash incidents in the city of Austin, Texas. Considering both types of data, this thesis aims to achieve a well-rounded quantification of the effect pedestrian control devices have on overall pedestrian safety. From the result of the first component of the investigation, the effect of a flexpost island is not significantly different from the effect of a marked crosswalk on driver yielding propensity. Significant differences were observed between yielding at concrete refuge islands and every other pairwise comparison to flexpost islands, marked crosswalks, and unmarked crosswalks. From the second component, interaction seems to exist between

treatment and both sidewalk presence and bus stop presence. The difference in fatality crashes at locations with and without pedestrian crossing treatments is less when there is no sidewalk present. Additionally, the difference between treatment presence on pedestrian fatality percentage is less when there is a bus stop more than 358 ft away.

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Introduction

Leveraging quantitative knowledge on pedestrian control devices can maximize the potential to reach various goals, such as creating more walkable communities and improving safety. Many fast-growing areas across the country have expressed a rising interest in reducing motor vehicle dependency by creating denser, more walkable, more bikeable communities. Understanding the effects of the built environment on motorist-pedestrian interactions can inform future implementation of such control devices to maximize the potential to reach safety goals, such as decreasing pedestrian injuries and fatalities.

In recent years, pedestrian traffic fatalities have increased while motorist traffic fatalities have decreased (Shinkle 2018). While numerous reasons could explain this trend in pedestrian versus motorist crashes, at the end of the day our society needs to keep in mind that crashes are preventable events. Categorically, crashes are a public health concern requiring examination to identify effective methods and policies to prevent them.

There are many interventions that can reduce pedestrian crashes, including clarifying the indications transmitted to the actors interacting in the traffic network via the built environment or even carrying out public education campaigns on local laws. Really, the most operational way of influencing people's decisions to cross or to yield, for example, is through the built environment. The fact that the leading cause of fatal pedestrian crashes is 'failure to yield' according the Fatality Analysis Reporting Systems (FARS) implies that the various facets that go into both motorist and pedestrian decisions leading up to crashes could use improvement. One of these facets is the behavioral responses that are triggered by people's surroundings. Presumably for some combination of reasons, the pedestrians involved in failure to yield crashes felt that they were able to cross safely. Improving our understanding about the effects the built environment has on human behavior can help with reducing traffic fatalities and prioritizing intervention.

By design, the built environment aims to make who has the right-of-way very clear by presenting expected, easy-to-interpret indications, such as yielding. Some environments are much clearer than others, for example a marked crosswalk versus an unmarked crosswalk. If there is a location where crashes between pedestrians and motorist occurs often and for the same reason, then the local entity in charge will consider interventions to improve the design of the pedestrian crash hot-spot location. If engineers and planners can anticipate or know the response that the built environment activates in both motorists and pedestrians, then there is a reasonable chance at maximizing these safety improvements.

Many cities have adopted a Vision Zero safety policy, an initiative that was originally envisioned by the Swedish, of reducing all traffic related fatalities to zero. In order to effectively eliminate all fatalities, then both sides of motorist-pedestrian interactions need attention. Since the leading cause of pedestrian fatalities has been attributed to 'failure to yield', the insights gleaned from fatality crashes offer more from the perspective of the pedestrian. That is, these data lend themselves more toward answering the question of what types of environments lead pedestrians to decide to fail to yield to motorists. On the other hand, the fatality crash data do not offer very much potential in terms of answering the opposite question of what types of environments lead motorist to fail to lead to pedestrians. Both scenarios are dangerous and can result in a traffic fatality, consequently both scenarios require evaluation to reach a Vision Zero goal.

The City of Austin is an example of a city with Vision Zero and goals to support walkability. Imagine Austin, City of Austin's plan to transition to a more multi-use, active transportation friendly city with affordable housing, and improved connectivity, exemplifies the city’s desire to improve non-motorized facilities. For cities, such as City of Austin, to transition to more active transportation-friendly environment, grasping the quantifiable effects that the built environment has on pedestrian-motorist interactions supports a proactive approach to combat the recent trend in rising pedestrian traffic-related deaths.

This thesis presents the results of an experimental study on driver yielding behavior toward pedestrians at various crossing treatments from an observational study of pedestrian crash incidents in the city of Austin, Texas. Using these results, this study quantifies the effect of pedestrian control devices on pedestrian fatalities. Considering both types of data, this thesis aims to achieve a well-rounded quantification of the effect pedestrian control devices have on overall pedestrian safety.

Literature Review

Compared to the rest of the United States, Texas sees some of the highest pedestrian crash rates. Pedestrian fatalities in car-related crashes account for 16% of all fatalities in the United States in 2018. The Federal Highway Administration (FHWA) has deemed Texas Bicycle and Pedestrian a focus state (Figure 1) because of the high number of pedestrian death rates, meaning FHWA has put additional resources into improving these statistics (FHWA 2015). In 2016, there were 31 pedestrian deaths in Austin, Texas, 637 in Texas, and 5,987 in the United States. Nearly 6,000 pedestrians have died between 2016-2017, marking a 25-year high in pedestrian fatalities (Governors Highway Safety Association 2017). Most of these crashes occurred in urban areas, at midblock locations, during after-dark hours.

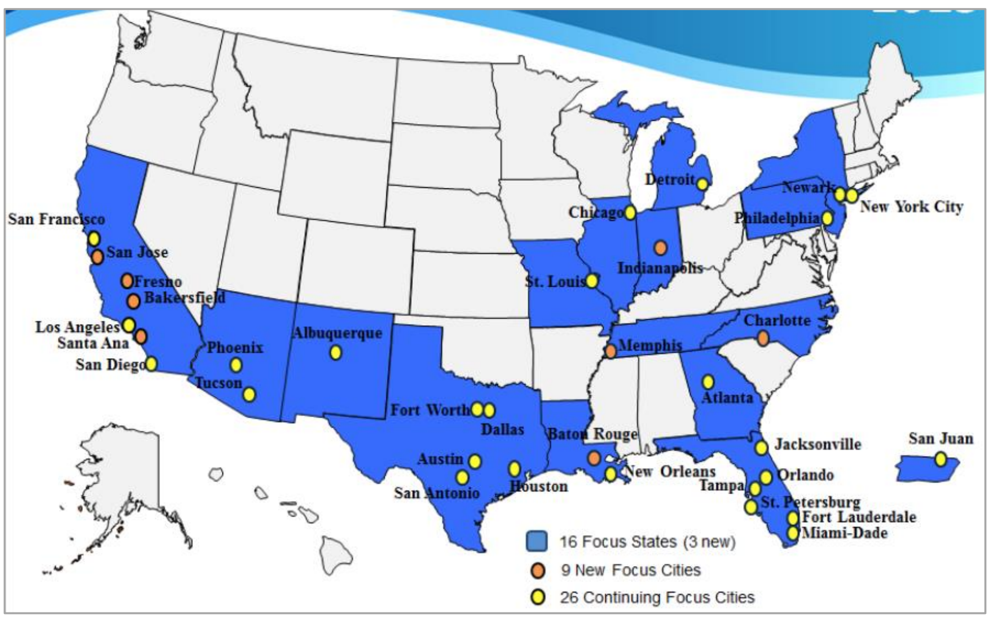

Figure 1 FHWA's Map of Pedestrian-Bicycle Focus Cities

With a Vision Zero and an improved walkability goal in mind, traffic engineers, urban planners, and cities must do everything possible to preemptively reduce traffic-related fatalities. As cities continue to grow and densify, people are increasingly looking at modes other than vehicles to get to their destinations. People choosing to walk to their destinations more and more can bring about many benefits, such as reduced pollution at the societal level and increased cardiovascular activity at the individual person level. Generally, this active transportation renaissance has increased the demand for effective pedestrian facilities to ensure a safe built environment.

EARLY RE-DEFINITION OF STREETS

Prior to the introduction of the automobile, city streets were filled with pedestrians at large. Not long after the introduction of the automobile, automobile users began criticizing the pedestrians using streets that had gradually become major thoroughfares. Around the 1910s was when the turf war between pedestrians and automobiles began and by the 1930s, the battle between pedestrians and automobile promoters had virtually ended. In the end, automobile promoters had won the backing to rebuild cities to accommodate and prioritize motorized vehicle travel (Norton 2008).

From the very beginning of multi-modal streets, traffic engineers have encountered challenges in balancing both safety and spatial efficiency of the transportation network. Even in the early re-definition of streets, these same competing goals were the anthems of pedestrians and automobile users. Pedestrians and parents of children were concerned with “death cars” and felt that they were fighting for justice in fighting against automobiles. At the same time, automobile promotors backed regulating traffic and making streets more auto-centric to improve efficiency of travel (Ladd 2008; Norton 2008). Over time, cities have come to realize that prioritizing one mode can decreased the quality of travel for other modes, and as a result have focused on improving facilities and public education on non-motorized travel modes.

The contemporary issue of ever-increasing congestion and ever decreasing space has led cities to try to alleviate the stress on the transportation network by reverting back to mixed-use spaces and non-motorized transportation modes. Planning for a dense community filled with affordable, mixed-use spaces can make it easier for city-dwellers to access destinations by walking or biking and can control motor vehicle dependency. The City of Austin is an example of a city that has recognized the following: urban sprawl driven by limited housing supply in central city areas can lead to motor-vehicle dependent, congested cities.

In 2012, the City of Austin published its municipal comprehensive plan that directly addressed the desire to make the city more dense, sustainable, and affordable (City of Austin 2012). The plan comments on facilitating walking and biking having the potential to promote community health by 1) reducing dependency on modes that produce greenhouse gas emissions and by 2) encouraging daily exercise. Imagine Austin is an example of a City that has planned to revert to the ways of the past by further prioritizing pedestrian and cyclist travel.

PEDESTRIAN CONTROL DEVICES

One way of encouraging safe pedestrian travel is through the implementation of control devices. The Manual of Uniform Traffic Control Devices (MUTCD) for Streets and Highways specifies national standards for all traffic control devices, including road markings, highway signs, and traffic signals (Federal Highway Administration 2009). In the context of pedestrian facilities, control devices can include: signs, beacons, signals, pavement, markings, and raised islands. Table 1 shows the corresponding section in the MUTCD for each type of approved pedestrian control device.

Table 1 Pedestrian Control Devices given by MUTCD, 2009 Edition

Control Device	Section	Title
Signs	2B.52	Pedestrian Crossing Signs
	2B.11	Yield/Stop Here for Ped Signs
	2B.52	Pedestrian Signs
Signals	4E.01	Pedestrian Signal Heads
Beacons	4F.01	Application of Pedestrian Hybrid Beacons
Pavement Markings	3B.15	Transverse Markings
	2B.18	Crosswalk Markings
Islands	3I.06	Pedestrian Islands and Medians

This study will recognize any of the aforementioned items as a ‘pedestrian control device’ and will treat unmarked crosswalks as locations without pedestrian control. To specify, unmarked crosswalks are locations pedestrians can legally cross. An unmarked crosswalk is the continuation of lines of a sidewalk across a road at an intersections as shown in Figure 2 (*image from City of Austin*).

Figure 2 Unmarked Crosswalk in Highlighted in Green.

New pedestrian facilities that are not specified by the MUTCD and do not have an Interim Approval will require an approved Request for Experimentation (RFE) before installation. An approved RFE requires the experimental sites to undergo a before and after study to determine the appropriateness of the design and its benefit to safety.

Figure 3 Pedestrian-Actuated Rectangular Rapid-Flashing Beacon

The only experimental pedestrian crossing improvement with active interim approval from FHWA is the pedestrian-actuated rectangular rapid-flashing beacon (RRFB). The RRFB is a relatively low-cost sign meant for use at uncontrolled crosswalks (Figure 3 *image from FHWA*). The pedestrian-actuated rectangular rapid-flashing beacon has shown high motorist yielding rates, higher even than standard yellow circular flashing warning beacons (Knopp 2018). While some studies have focused on new crossing types, there are no experimental signs or signals included in the analysis presented in this thesis.

PREVIOUS STUDIES ON PEDESTRIAN CONTROL DEVICES

This section reviews previous research on the relationship between driver yielding behavior and control devices. Knowing what kinds of facilities and combinations of facilities work best under different conditions is essential to improving pedestrian safety. Previous studies and experiments have explored: the use of surrogate measures (NHSTA 2006; Stapleton et al. 2017), yielding at beacons (Western Michigan University 2016; Fitzpatrick et al. 2014), yielding at in-street sign gateways (Bennett 2013; Western Michigan University 2016), yielding marked versus unmarked crosswalks (Zegeer et al. 2001), and the factors that may predict the likelihood of yielding (Schroeder and Rouphail 2011). The majority of experiments testing driver yielding behavior resorted to using decoys and staged crossings to ensure significant sample sizes are obtained in a timely fashion.

A concern with respect to designing human behavior experiments is whether the use of decoys provides results that are representative of the real world. Studies typically rely on video collection of either staged or natural to collect pedestrian data. When using staged data, the short answer to the previous question is not necessarily. A study that compared staged and non-staged pedestrian crossings found no statistical significance in yielding results (Fitzpatrick et al. 2015), however, when using a staged approach, the variability in pedestrian behavior disappears. Differences in pedestrian aggression can affect how the pedestrian attempts to cross a location, which will in turn affect the driver’s response.

Surrogate Measures

One of the main challenges in the safety analysis component of pedestrian crossing studies is the lack of crash data. Some large-scale, naturalistic observational studies have been conducted using cameras to create a database containing greater information about pre-crash and crash events (NHSTA 2006). The lack of adequate crash data is likely attributed to the fact that there are far more collisions and conflicts occurring than are reported to the police (NHSTA 2006). Typically, the majority of crashes result in damages less than the dollar amount threshold for a property damage only (PDO) report in the opinion of the reporting police officer. In this context, a safety surrogate can overcome the lack of vehicle-pedestrian crash and conflict data due to the rarity of such events. According to a large study, the approach of using conflicts as surrogate for crash data is an acceptable estimation of crash risk (NHSTA 2006). Therefore, vehicle compliance can serve as a surrogate for vehicle-pedestrian crashes or conflicts.

Yielding at Pedestrian Beacons

Studies reviewing yielding rates at pedestrian-actuated rectangular rapid-flashing beacons (RRFB) and pedestrian hybrid beacons (PHB) have observed high yielding rates. Figure 3 shows an example of a user-activated RRFB, which is used to supplement standard crossing warning signs and markings. RRFBs flashes at a much faster pulsing rate and shines more brightly than the standard flashing beacon (Sundstrom and Nabors 2014). On the other hand, a PHB flashes yellow and red to alert drivers to slow and then stop for pedestrians as shown in

Figure 4 (*images from the City of Austin*). PHB are most appropriate for multi-lane or higher speed or volume roads (Sundstrom and Nabors 2014).

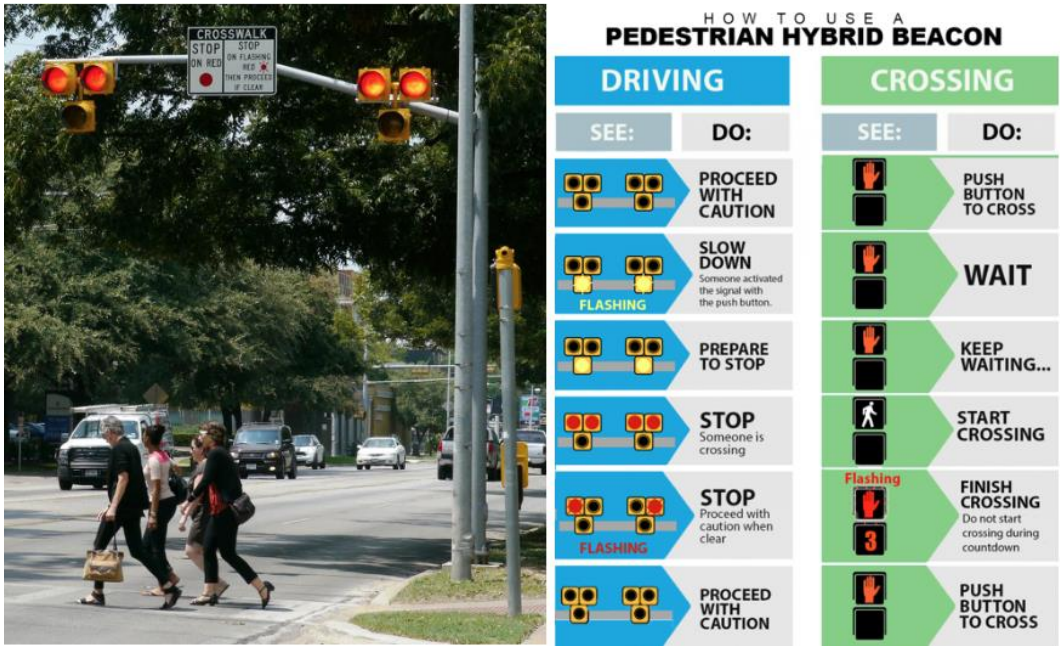

Figure 4 Pedestrian Hybrid Beacon Image and 'How-To' Infographic

An experimental study conducted in Texas tested driver yielding behavior Traffic Control Signals (TCSs), RRFBs, PHBs, and found yielding for RRFBs and PHBs were 86% and 89%, respectively (Fitzpatrick et al. 2014). In Michigan, a review of 31 sites found that compliance ranged between 95% and 100%. Moreover, other research published by FHWA shows that PHBs average 96% yielding compliance (Fitzpatrick et al. 2016).

While these yielding rates are much better than what has been documented at unmarked and marked crosswalks, these treatments are typically much more expensive. A PHB can cost approximately $75,000 to install (City of Austin n.d.). And although RRFBs are considered a lower cost alternative ranging from $10,000-$15,000 to implement (FHWA 2009), RRFBs are still more expensive than a marked crosswalk.

Yielding at Gateway Formations

Implementation of in-street signage in gateway formation, such as R1-6 signs, can improve yielding rates as much as costly PHB and RRFB signs (Bennett, Manal, and Van Houten 2014; Bennett and Van Houten 2016; Hochmuth and Van Houten 2018; Van Houten et al. 2018). A gateway installation has one in-street sign installed between the travel lanes in each direction, and one on both edges of the roadway in each direction. Figure 5 (*from Hochmuth and Van Houten 2018)* shows the R1-6 in-street sign in gateway formation. For comparison, a single R1-6 sign with a fixed base costs less than $300.

Bennett, Manal, and Van Houten 2014 showed that the in-street gateway configuration increased yielding to a level similar to PHBs and RRFB signs. Yielding rate without signage was 23% and increased to 82% with the gateway configuration. A few years later, Bennett and Van Houten showed using fluorescent signs without the yielding message in a gateway formation increased yielding from 7% to 33% but adding the yielding increased yielding rates from 33% to 78%. Most recently, Van Houten et al. 2018 showed that yielding remained consistently high at permanent gateway installations with little to no evidence of decline nine months post installation.

Figure 5 Gateway Configuration

Yielding at Marked Crosswalks

A number of studies have evaluated pedestrian safety at marked crosswalks and have reported a wide range of yielding rates. One of the early studies on marked crosswalks conducted in the City of San Diego concluded that marked crosswalks had more pedestrian collisions than unmarked crosswalks (Herms 1972), and led some people to interpreting marked crosswalks as being less safe. As a result, there has been controversy over whether or not marked crosswalks at uncontrolled locations improve pedestrian safety.

More recently, Zegeer et al. 2001 reviewed crash rates at marked and unmarked crosswalks at locations to determine the safety effects of marked crosswalks. The study revealed that on two-lane roads there is no difference in pedestrian crash rates when comparing marked and unmarked crosswalks. At multilane locations, marked crosswalks were associated with a higher pedestrian crash rate. Perhaps the increase in crashes at marked locations is caused by pedestrians feeling a false sense of security and as a result acting in a less cautious manner.

Marked crosswalk compliance has high variance with values reported in the literature. The baseline results from a study evaluating whether a raised arm or similar prompt could improve driver yielding in Chicago and Michigan show the wide range of observed yielding rates at marked crosswalks. In the baseline case with no arm raised, yielding rates at marked crosswalks with no signs in Chicago and Michigan ranged between 1.9% and 31.5% (Crowley-Koch, Van Houten, and Lim 2011). Differences in laws or law enforcement, pedestrian volumes, and societal norms may explain this large variance in yielding compliance.

Pedestrian Laws and Perspectives in the United States

Across the United States, approaching drivers who have enough time to see a pedestrian in the crosswalk must let the person cross by law. However, these laws are not strictly followed and rarely enforced. A survey-based study conducted across 171 cities across North America presented the perceptions of driver yielding behavior held by pedestrian safety professionals (Schneider and Sanders 2015). Respondents gave evidence of differing driver yielding culture between communities, rare enforcement, and increased yielding rates on narrow, low speed highways. The professionals that were surveyed identified a number of factors to be even more influential to driver yielding than vehicle volume, driver alertness, and pedestrian visibility, such as driver behavioral norms; enforcement of laws; and pedestrian behavioral norms. Figure 6 illustrates the hierarchy of causes for driver yielding as interpreted by the study of North American perspectives (Schneider and Sanders 2015).

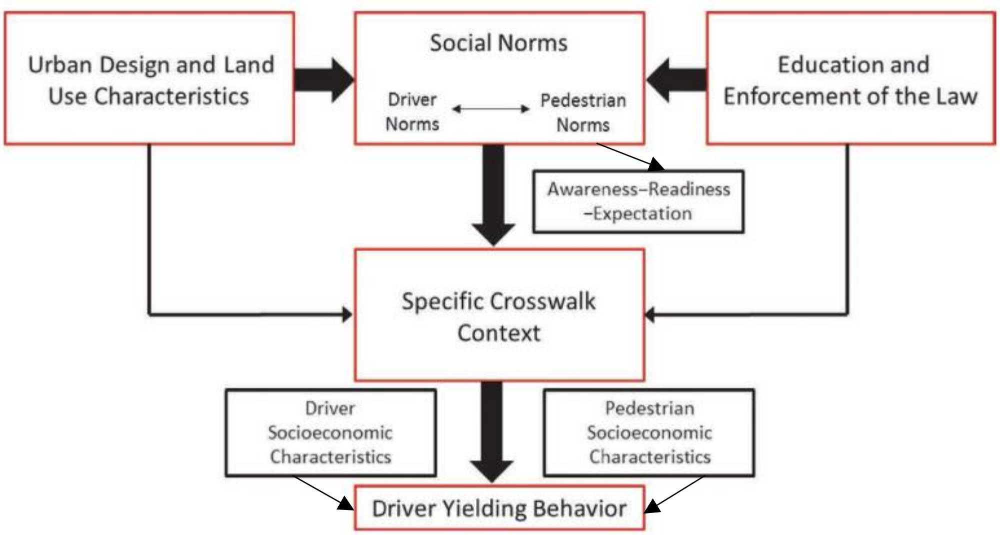

Figure 6 Factors that influence driver yielding behavior

In Figure 6 the items in the top are community-level factors, the middle row consists of site-level factors, and the bottom row represents the driver's compliance (*figure modified from Schneider and Sanders 2015*). Items boxed in red are major factors and items boxed in black are minor factors influencing driver yielding. The various arrows indicate the different paths of influence that factors may take. The thicker arrows indicate the most common path (Schneider and Sanders 2015).

As indicated in the figure, 'Education and Enforcement' is a major factor in influencing yielding behavior. Most states only require motorists to yield to pedestrians in uncontrolled crosswalks; only nine states require that motorists come to a stop for pedestrians in certain situations. Minnesota is the only state in the U.S. to require motorists to stop for pedestrians in any portion of the roadway (Shinkle 2018). Texas requires that drivers give the right of way to pedestrians at uncontrolled intersections, if the pedestrian has a walk signal, and if there is a pedestrian in the street (TxDPS 2017). Indeed, education is one piece of the puzzle for improving pedestrian safety. But, achieving a built environment with expected, easy-to-interpret indications can overcome educational shortcomings.

Cities facing rapid growth or have high international tourism, such as London and New York City, are at risk for even more pedestrian safety issues related to lack of knowledge about the local urban design. In both of these cities, the municipal authority has decided to paint markings to remind pedestrians where to look before crossing the street. London, for example, has taken steps to clarify the rules of built environment by placing the phrase 'Look Right' at crosswalk endpoints. Painting explicit instructions as a safety measure to remind pedestrians that the societal norms and laws are different from other countries is an extreme example of delivering easy-to-interpret indications through the built environment.

FACTORS INFLUENCING DRIVER YIELDING BEHAVIOR

The results of past studies show that pedestrian facilities can improve safety, and that certain combinations of treatments and motorist characteristics influence compliance rates. The following list summarizes some notable findings from previous work:

- *Driver approach speed impacts yielding compliance* (Bertulis and Dulaski 2014)

An inverse correlation exists between vehicle speed and yielding rates. Based on the observed data, there is a linear relationship between measured vehicle speed and yielding rates with an R^2 of 0.99.

- *Vehicles traveling at higher speeds and or within platoons have lower yield rates* (Schroeder and Rouphail 2011; Bertulis and Dulaski 2014).

Pedestrians are less visible to cars traveling behind the leading car in a platoon. Additionally, non-yielding cars might influence other approaching cars, meaning a motorist is less likely to yield to a pedestrian if none of the other motorists are yielding.

- *Pedestrian characteristics influence motorist yield rates*

Motorists are more likely to yield to more assertive pedestrians or those situated in a large group which, again, may be related to their increased visibility (Turner et al. 2006; Schroeder and Rouphail 2011).

- *Crosswalk type strongly influences motorist yield rates*

Yielding rates can range from a low as less than 5% compliance at marked crosswalks (Crowley-Koch, Van Houten, and Lim 2011) to as much as 96% at PHBs (Fitzpatrick et al. 2016).

- *Red signals and other beacon devices are the most effective crossing treatment for larger arterials* (Turner et al. 2006)

Motorist yielding compliance at sites on busy arterial streets with red signal or beacon signs were 94% or higher in both the staged and natural crossing data (Turner et al. 2006). Gateways and signage alone are likely less effective on wider roadways with higher speed limits and traffic volume where they are more susceptible to damage and are less obvious than pedestrian signals and flashing beacons.

SUMMARY

This chapter reviewed previous research on pedestrian control devices and pedestrian safety. Based on past research, it can be expected that driver yielding rates may be improved by:

- Installing pedestrian signals at crossings on arterials;
- Installing in-street signs in gateway formation, which can be as effective as expensive PHB and RRFB signs;
- Improving the visibility of pedestrians;
- Providing education regarding pedestrian crossing facilities to increase familiarity; and
- Reducing speed limits.

The following chapter reviews the methodology used to investigate the effect of different combinations of pedestrian control devices in various roadway environments, in terms of driver yielding and crash rates.

Methodology

INTRODUCTION

In order to investigate the effects crossing treatments have on pedestrian safety, the rest of this thesis is broken up into two major components. The first component focuses on the relationship between motorists and pedestrians by comparing yielding rates among various crossing treatments using the results from an experimental study. In general, crashes are considered rare events, resulting in relatively small sample sizes. Yielding rates can serve as a proxy for potential crashes and be used to generate conclusions about the built environment's impact on safety.

To complement the first portion of the analysis, the second component considers the presence and type of crossing treatments and their effect on fatal pedestrian crash rates. Both the experimental yielding analysis and exploratory fatal crash analysis use data collected in Austin, Texas.

EFFECT OF CROSSING TREATMENTS ON YIELDING RATES

This experiment was conducted using staged-crossings made by a single decoy at ten locations varying in terms of control devices and other characteristics. The overarching questions explored in this study are:

1. How does driver yielding behavior change with respect to crossing treatment type?
2. How does driver yielding behavior change with respect to signage type?

This section reviews the study locations, the decoy crossing technique, the data collection process, and an overview of the statistical tools used for the data analysis portion of this study.

Site Selection

Ten sites were chosen that have characteristics common to low-volume, residential roadways in the Austin, Texas area and include a variety of crossing and signage types. For this study, four crossing types and five signage types were considered. Table 2 shows the complete list of sites and related characteristics and contains the following pieces of data:

- Treatment,
- Crossing Type,
- Signage Type,
- Street to Cross,
- Nearest Cross Street[1],
- Speed Limit,
- Number of Lanes to Cross,
- Intersection Geometry,
- Land-Use, and
- Number of Pedestrian-Vehicle interactions.

A treatment is a unique combination of crossing type and signage. The section below defines each crossing type and signage type included in this study. Street to Cross refers to the street crossed by the decoy. For the most part, each location included in the experiment was indeed an intersection. Number of Lanes to Cross are the total number of motor vehicle travel lanes crossed by the decoy when crossing from one side of the intersection to the other. Note that the intersections with an asterisk listed next to their number of lanes indicates that the intersection also contains bicycle lanes. Intersection Geometry indicates the general intersection geometry of the experimental location, which could be a four

[1] There were some locations that were not intersections, therefore, *Street to Cross* could indicate the nearest intersecting street.

leg (+) intersection, a three leg (T) intersection, or a mid-block (I) location. Land-Use describes the purpose of the built environment adjacent to the experimental location. Lastly, Number of Pedestrian-Vehicle Interactions is the total number of times the decoy crossed using the crossing facility with a vehicle present in the designated yielding decision zone. The yielding decision zone will be discussed in further detail later on.

Table 2 Treatment Types and Site Characteristics

Treatment	Crossing Type	Signage Type	Street to Cross	Nearest Cross Street	Speed Limit	# Lanes to Cross	Geometry	Land Use	# of Observed Ped-Veh Interactions
A	Concrete Refuge Island	Reg Combo	North Loop	Chesterfield	30	2*	T	residential	65
B	Flexpost Refuge Island	W11-2 Only	Lakeshore	Ladybird	40	2*	T	park	68
			Springdale	Norwood Hill	40	2*	T	residential	80
C	Marked Crosswalk	Family Only	51st	Eilers	30	2*	+	residential	86
D	Marked Crosswalk	W11-2 Only	W 30th	Hemphill	30	2	+	park	48
			Bullcreek	Jackson	35	2*	T	residential	94
E	Marked Crosswalk	Warn Combo	Chestnut	17th	25	2*	+	residential	42
F	Unmarked Crosswalk	Warn Combo	Chestnut	16th	25	2*	+	park	32
			Chestnut	21st	30	2*	+	residential	42
			51st	Martin	30	2*	+	residential	67

*Location has bicycle lanes.

The crossing types included in this experiment are: marked crosswalks (Figure 7), unmarked crosswalks (Figure 8), concrete refuge islands (Figure 9), and flexpost refuge islands (Figure 10). Listed below are the descriptions of the crossing types:

Marked crosswalk: path demarcated by painted stripes on the roadway for pedestrian crossings.

Unmarked crosswalk: undefined crossing path, may include ramps down from the sidewalk to the road, and can be thought of as an extension of a sidewalk across an intersection.

Concrete Refuge Island: a raised median at the centerline of a roadway on which a pedestrian may stop halfway when crossing.

Flexpost Refuge Island: an area delineated by flexposts at the centerline of a roadway on which a pedestrian may stop halfway when crossing.

Figure 7 Marked crosswalk at 30th & Hemphill

Figure 8 Unmarked crosswalk at 51st & Eilers

Figure 9 Concrete refuge island at North Loop & Chesterfield

Figure 10 Flexpost refuge island at Springdale & Norwood

The signs located at the selected sights include: W11-2 (Figure 11), advanced warning signs (Figure 12), family (Figure 13), and R1-6 (Figure 14). Listed below are the descriptions of the sign designation types used:

W11-2 Only: there are only W11-2 signs adjacent to the crossing.

Family Only: there are only Family signs adjacent to the crossing.

Reg Combo: there is some combination of regular signs (W11-2, R1-6, and/or family) adjacent to the crossing, but not including an advanced warning sign.

Warn Combo: there is some combination of regular signs (W11-2, R1-6, and/or family) adjacent to the crossing with an advanced warning sign.

Figure 11 W11-2 sign at Chestnut Ave & 17th

Figure 12 Advanced warning sign at Chestnut Ave & 17th

Figure 13 Family sign at 51st & Eilers

Figure 14 R1-6 yield signs at North Loop & Chesterfield

Data Collection

At each location, a minimum of 30 interactions were recorded. An interaction was defined as any moment where the pedestrian decoy attempted to cross the intersection following the proper crossing technique and a car was present within the designated zone. The few instances where the decoy either indicated his intention to cross too late or too early were not considered in the data analysis. As mentioned in the Literature Review, when using a staged approach, the variability in pedestrian behavior disappears. The differences in pedestrian aggression can affect how a pedestrian attempts to cross a location, which in turn can affect the driver's response. The focus of this study was isolating the response of drivers, consequently losing the variability in pedestrian behaviors was intentional.

For each site, the camera was positioned so that the crosswalk was visible as well as the intersection approach of interest. The goal was to have full sight of the decoy's position at the crosswalk as well as the approaching traffic at the yielding decision zone. The yielding decision zone is the last point at which a driver could make the decision to safely yield to a pedestrian.

Initially, the stopping sight distance (SSD) formula was used to estimate the appropriate area to use as the yielding decision zone. However, during initial testing, these distances were generally unrepresentative of natural pedestrian crossing behavior. This was likely because the SSD was calculated using the speed limit, which does not necessarily represent the actual speed of vehicles near the crossing. Using the calculated SSD as the car position when the pedestrian decoy would attempt to cross left the decoy plenty of time to cross without any perceivable reaction from the motorist. Therefore, a slightly shorter distance was used to represent more natural crossing and yielding interactions. A common yielding decision zone distance, 150 to 180 feet from the crosswalk, was used to test every intersection despite minor differences in speed limit across sites. This yielding decision zone where the motorist can choose to safely yield to those in the crosswalk or not was marked using a measuring wheel at each location. In the video recording, this location was marked by the decoy via a hand wave to the camera to clearly indicate the zone for those processing the data later.

While these were the intended procedures, the yielding decision zone was not always easily determined during the post-data collection review process. In most cases, the decoy raised his arms in the video after measuring out 150-180 feet; however, in just a small number of cases it was necessary to use the measuring tool in Google Maps to find a corresponding reference point in the video for the yielding decision zone. For cases were Google Maps was out of date, it was assumed that the decoy was indicating intent to cross at the appropriate times. These issues do not apply to the majority of the data collected in this experiment; however, mentioning these details may help others improve these techniques in future experimentation.

When reviewing the video footage, all interactions between vehicles and the decoy were recorded. Every vehicle that slowed or came to a stop when the decoy was exhibiting his intent to cross was counted as a 'yield' interaction. Every vehicle that neither slowed nor came to a stop for the decoy was counted as a 'no yield' interaction. Instances when the decoy attempted to cross after the vehicle had passed the yielding decision zone were not counted. Information on whether the vehicle was present in the half of the roadway in which the pedestrian was present or on the far side of the road was also tallied.

Crossing Technique

The crossing technique used in this experiment was largely based on previous experiments (Van Houten, Laplante, and Gustafson 2012; Fitzpatrick, Turner, and Brewer 2007; Stapleton et al. 2017). One study conducted in Michigan at 31 sites across three universities studied the relative effectiveness of various roadway treatments and signs used at midblock crossings (Stapleton et al. 2017) was especially helpful to this experiment. The Michigan study recorded decoy pedestrians to determine yielding behavior and used level of compliance as a surrogate for safety at the crossings used. This experiment differs by having the decoy remain in the crossing position after a vehicle has failed to yield to test the next vehicle for compliance until a vehicle yields or until there are no more vehicles in sight. Following this procedure allows observation of yielding rates for vehicles belonging to platoons. Shown below is the method utilized by the decoy pedestrian for this experiment.

1. Approach the crossing when a vehicle is in sight.
2. When the vehicle reaches the yielding decision zone, lean upper body or step into the crosswalk while making eye contact to indicate intention to cross.
3. If the approaching vehicle begins to yield, make the crossing while maintaining eye contact with the driver.
4. If additional vehicles are approaching from different lanes, wait until the intention of the vehicle in the next lane is ascertained.
5. If the approaching vehicle does not yield and there is another vehicle in sight, remain in position at the edge of the crosswalk and make another attempt to cross using the same technique.
6. If the approaching vehicle does not yield and there is not another vehicle in sight, move away from the crosswalk and return to step 1.

In addition to this method, some conditions were used to reduce the number of variables that may affect driver yielding as well as to promote consistency in data collection and analysis.

- Do not consider a crossing if there are other pedestrians attempting to cross at the same location.
- If crossing multiple lanes, the yielding assessment for the next lane to cross should be made only once the decoy has reached the center of the current lane. Meaning, each lane was considered individually with the decoy approaching the centerline as he would the curb. If, after crossing through the nearest lane in front of a yielding car, there were no cars

approaching in the next lanes to cross or there was plenty of time for the decoy to cross, those cars were not counted as interactions.

- Do not count any crossings where a turning vehicle appears to yield to the decoy because it is impossible to tell whether car was yielding or simply slowing down to turn.
- Do not count any crossings where the decoy accidentally indicates intention to cross too late, meaning the vehicle has already passed through the yielding decision zone and no longer has enough time to stop.
- Count opposing directions of traffic as separate pedestrian-motorist interactions.

EFFECT OF CROSSING TREATMENT ON CRASH RATES

Fatal pedestrian crash data from Austin, Texas were collected to observe the effect of the presence of a nearby pedestrian control device on pedestrian safety. Austin, Texas was selected as the geographic location to allow for comparison between these results and the results from the yielding experiment. The two main questions asked are:

1. What is the effect of a pedestrian crossing facility on fatal crashes?
2. What is the effect of bus stop proximity on pedestrian fatal crashes?

The next section reviews the data collection technique along with the assumptions used in the analysis.

Data Collection

To answer the aforementioned questions, two main data sources were used. The first database accessed was the Fatality Analysis Reporting System (FARS) and the second was the Texas Department of Transportation’s (TxDOT) Crash Records

Information System (CRIS) database. Maintained by the National Highway Traffic Safety Administration (NHSTA), the FARS database contains a nationwide census on traffic-related fatalities. The CRIS database contains all crash data submitted by Texas law enforcement officers. The CRIS data contain information on all reportable crashes in the State of Texas. Reportable crashes are crashes, in the opinion of the reporting officer, that meet the damage threshold of $1,000 required for a property damage only (PDO) crash report. Therefore, the CRIS data do not contain information on low-damage crashes. Meaning, there are potentially many incidents between pedestrians and cars that are not present in the dataset.

Crash data were extracted using the online public query tools available for both FARS and CRIS. The proportion of the number of fatal crashes (from FARS) out of the total number of all types of crashes (from CRIS) was the metric used in the evaluation. Location-specific crash data are relatively scarce and require either an increase in geographic or in time span to obtain a large enough sample. As done in most crash analyses, the analysis period for Austin, Texas pedestrian crash data analysis is three years (2015, 2016, and 2017) a decent sample.

Crash Categorization Process

Upon reviewing the crash data in detail, it was clear that many of these crashes occurred at mid-block, non-intersection locations. Consequently, there were not enough samples of crashes occurring at exact locations where a marked or unmarked pedestrian facility could exist. To overcome this challenge and make use of all of the crash data, the following assumptions were adopted:

- A typical block distance represents a reasonable, accessible distance for a crossing facility for pedestrians of all abilities.

- A pedestrian crash is categorized as 'treatment present' if the crash occurred at a location with a perpendicular pedestrian facility (marked or unmarked) present within a typical one-block distance of 358 ft. If the crossing facility is unmarked, then there must be a sidewalk present parallel to the crossing direction.
- A treatment is categorized as 'marked' if treatment contains any of the pedestrian control devices listed in Table 1.

For example, an unmarked crosswalk within 358 ft of a crash location would be categorized as 'treatment present' and 'unmarked'. On the other hand, a marked crosswalk within 500 ft of a crash location would be marked as 'treatment not present' under this scheme. The following shows the sequential steps involved in categorizing each of the crash data points using the methodology above.

Step 1. Locate crash using an up-to-date mapping service.

The Google Maps tool was used to locate and contextualize crash data points with longitude and latitude coordinates. Both the map view and the street view were used to determine specific information.

Step 2. Compare the crash date to the date of the of the street-view image.

One of the main downfalls with considering multiple years of data lies in the fact the built environment may change over time. The street view provided by Google Maps has the date listed in the tool and allows the user to go back in time. Changes in the potential built environment were checked for each data point to ensure accuracy in the categorization process.

Step 3. Categorize the data point in terms of pedestrian crossing facility presence and type.

As mentioned before, a pedestrian crash is categorized as having a treatment present if the crash occurs at a location with a perpendicular pedestrian facility within a reasonable and accessible distance of 358 ft (~ 1.5 minute walk). A marked crossing facility can have any of the pedestrian control devices listed in Table 1.

If the crossing facility is unmarked, then there must be a sidewalk present parallel to the crossing direction.

If there is no sidewalk and no markings within the 358 ft zone, then the crash is considered as occurring at a location with 'no treatment'.

Step 4. Categorize the data point as either a legal or illegal crossing.

Environments are designed assuming that travelers (motorist and non-motorists) will follow laws and indications. Generally speaking, the built environment will not improve crash incidence under illegal crossing conditions. Education and enforcement can more appropriately target crashes occurring under illegal crossing. On the contrary, information from crashes related to legal crossing scenarios are more appropriate for guiding improvements to the built environment. Since this thesis focuses on the effect of the built environment on pedestrian safety, crashes occurring under legal crossing scenarios are the ones of interest.

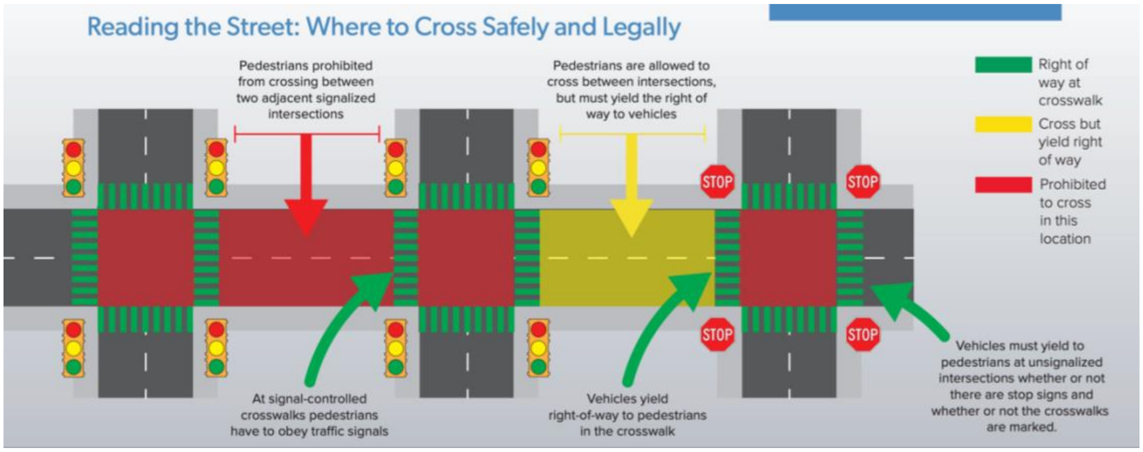

Figure 15 Legal and Illegal Crossing Scenarios in Texas

Figure 15 (*from City of Austin 2018*) shows the various types of legal pedestrian crossings allowed in Texas. The areas in green and yellow show areas where a pedestrian is allowed to cross. Green indicates that the pedestrian has the right of way whereas yellow indicates the motorist has the right of way and the pedestrian should yield way to vehicles. Pedestrians are prohibited from crossing in locations highlighted in red.

Step 5. If treatment is present, categorize the data point terms of treatment markings.

Pedestrian crossing facility visibility should, in theory, improve pedestrian safety. Tallying marked crossing facilities will allow verification of this hypothesis.

This process was repeated for all 86 fatal pedestrian crash data points that occurred in Austin, Texas.

ANALYSIS OF VARIANCE

Both one-way and two-way analyses of variance (ANOVA) were used measure the effect of pedestrian control devices on driver yielding and fatality crash rates. Vehicle platooning was also tested in conjunction with pedestrian control devices to see if a driver's disposition to yield to a pedestrian was different when traveling in a platoon of vehicles versus not. In the experimental portion of this study, the decoy remained in the crossing position until a vehicle yielded or until there were no more vehicles in sight, therefore capturing the platooning effect.

ONE-WAY ANALYSIS OF VARIANCE

One-way (ANOVA) is commonly used to evaluate whether a difference in response exists among different treatments present in an experiment. Experimental factors can be either continuous or categorical. In one-way ANOVA, the model only considers a single factor containing multiple factor levels as the predictor for the response variable. For example, if the factor is crossing treatment, then the different levels of the factor could be the individual treatment types (concrete refuge island, marked crosswalk, unmarked crosswalk, etc.) and the response could be driver yielding rates. The null hypothesis tests whether the factor level means (yielding rate or crash rate) are equal to each other. ANOVA essentially works as an extension of the t-test but overcomes the difficulty of losing statistical power associated with conducting multiple t-tests. ANOVA assumes that equal variance for every group is normally distributed and can yield inaccurate result if these assumptions are violated. However, ANOVA has been shown as an overall robust tool despite violations (Schmider et al. 2010). This one-way ANOVA test was performed using the Statistical Analysis System (SAS).

Factor Effects Model

Analyzing a single factor study begins with testing if all the factor means are equal with the overall F-test. The null hypothesis is the mean of every factor level is the same,

$$H_0: \mu_1 = \mu_2 \ldots = \mu_r,$$

where μ is the mean of a particular factor level and r is the number of factor levels. The test statistic used to test that hypothesis is

$$F^* = \frac{MSTR}{MSE},$$

where the MSTR is the mean square of the treatment and the MSE is the mean square of the error. Large values of F^* are evidence against the null, therefore the test essentially testing

$$H_0\colon E\{F\} = 1.$$

The alternative but totally equivalent formulation of the one-way ANOVA model is called the factor effects model. The treatment means, μ_i, are expressed as

$$\mu_i = \mu. + (\mu_i - \mu.) = \mu. + \tau_i,$$

where t_i is the effect of factor i. This study will use the factor effect formulation to determine the effect of each pedestrian control device. Therefore, the null hypothesis is

$$H_0\colon \tau_1 = \tau_2 \dots = \tau_r = 0.$$

Pairwise Comparisons

After obtaining a significant overall F-test result, the next step involves conducting a more detailed analysis. Namely, a significant F-test shows that the effect of each treatment is different, but what it does not provide is by how much. We can answer that question by obtaining pairwise comparisons of each treatment and the 95% confidence interval estimate for the difference between treatments.

If the only comparisons of interest are pairwise comparisons, then the Tukey adjustment is the preferred method for capping the family-wise error rate. The family-wise error rate is the probability of committing at least one Type 1 error. As the number of hypothesis tests increases, the probability of a false positive result increases by

$$1 - (0.95)^n,$$

where n is the number of tests. To cap the probability of a false positive, there are multiple corrections available, such as the Bonferroni procedure. In the case of running all pairwise comparisons, that is comparing all possible pairs of treatments, then a Tukey adjustment is recommended because it has more power and narrower confidence intervals compared to the Bonferroni procedure.

The tests for the pairwise comparisons are of the form

$$H_0: \mu_i = \mu_j$$

or

$$H_0: \mu_i - \mu_j = 0,$$

where μ_i is one factor level and μ_j is the other factor level of interest. If 0 shows up in the confidence interval estimate for this difference, then the null hypothesis cannot be rejected.

TWO-WAY ANALYSIS OF VARIANCE

Two-way ANOVA functions as an extension of one-way ANOVA, and tests whether there is any interaction between the two factors. Interaction happens when the effect of one factor depends on the level of the other. Two-way ANOVA takes two factors into account, Factor A and Factor B, with both Factor A and Factor B containing multiple factor levels.

This study selected both crossing type or signage type as Factor A and platooning as Factor B. The combinations of factor levels within Factor A and factor levels within Factor B are called treatments. Thus, the two-way ANVOA null hypothesis states that there is no difference in response between treatment means. Two-way ANOVA tests three null hypotheses: the means of the response variable are equal for different levels of Factor A; the means are equal for different levels of the Factor B; and that there is no interaction (the effects of one nominal variable do not depend on the value of the other nominal variable). After the performance of two-way ANOVA, pairwise comparison may be conducted to evaluate the difference in treatment effects between groups.

Model with One Case per Treatment

A fairly common circumstance in two-factor studies is when there is only one case per combinations of factors (treatments). In this study, there is only one measurement for each treatment. With only one measurement per treatment, the standard two-way ANOVA model does not work because there is no estimate of the error variance σ^2. In the standard formulation, the expected value of the mean square of interaction term (MSAB) is

$$\sigma^2 + n\frac{\sum\sum(\alpha\beta)_{ij}^2}{(a-1)(b-1)},$$

where $\sum\sum(\alpha\beta)_{ij}^2$ is the sum of squares of the interaction (SSAB) term and $a-1$ is the degrees of freedom for Factor A and $b-1$ is the degrees of freedom for Factor B. If there is no interaction, SSAB is equal to zero. Therefore, the second term in the equation zeros out and the MSAB becomes an estimator of σ^2.

SUMMARY

This chapter reviewed the methodology for the driver yield analysis and the pedestrian crash analysis. For the driver yielding experimentation, this chapter described the site selection, data collection process, and the crossing technique used by the pedestrian decoy. For the crash data observational study, this chapter described the data collection and the crash categorization process. Finally, the various types of statistical models that were used to analyze the data were also described. The following chapter details the results of both analysis components and interprets the results.

Numerical Analysis and Result Discussion

EFFECT OF CROSSING TREATMENT ON PEDESTRIAN YIELDING RATES

This first part of this chapter describes the results from the data collection effort and the statistical tests that were used to examine the motorist yielding behavior toward a pedestrian with respect to various pedestrian control devices. The investigation evaluated driver yielding behavior rates with respect to crossing type and signage type, separately. Additionally, the effect of traveling in a platoon was also tested in conjunction with the effect of control devices to see if it explained additional variability. The null hypothesis for all of these statistical tests is there is no difference between the yielding mean of a specific group (crossing type, signage type, platoon) and the overall yielding mean.

The first step in the analysis calculated yielding percentages for each site by tallying the total number of interactions in which a driver yielded and the number of interactions in which a driver did not yield out of the total number of interactions. The figures showing overall statistics (Table 3 and Figure 16) were calculated using an average of both near lane and far lane observations. Table 2 in the Methodology chapter contains a more detailed table of site characteristics.

The number of instances where a car was present in the near side (on the half of the roadway where the pedestrian was crossing) versus the far side (on the half of the roadway opposite of where the pedestrian was crossing) did not have an equal number of observations. Therefore, for some intersections the total number of observations for vehicles in the far lane is less than the minimum recommended sample size of approximately 30 observations. For that reason, the near lane versus far lane analysis was not submitted to additional statistical testing.

Table 3 Data Collection Summary

Intersection	Factor Crossing	Factor Signage	Total Near Lane Obs (#)	Near Yield %	Total Far Lane Obs (#)	Far Yield %	Total Obs (#)	Overall Yielding Average %
North Loop & Chesterfield	1	3	30	66.67%	3	33.33%	33	63.64%
Lakeshore & Ladybird Lake	2	1	39	20.51%	29	20.69%	68	20.59%
Springdale & Norwood	2	1	23	4.35%	5	0.00%	28	3.57%
51st & Eilers	3	2	38	13.16%	15	6.67%	53	11.32%
W 30th & Hemphill	3	1	42	35.71%	6	0.00%	48	31.25%
Bullcreek & Jackson	3	1	63	9.52%	31	0.00%	94	6.38%
Chestnut & 17th	3	4	36	11.11%	6	16.67%	42	11.90%
Chestnut & 16th	4	4	30	3.33%	2	0.00%	32	3.13%
Chestnut & 21st	4	4	39	0.00%	3	0.00%	42	0.00%
51st & Martin	4	4	52	1.92%	15	6.67%	67	2.99%

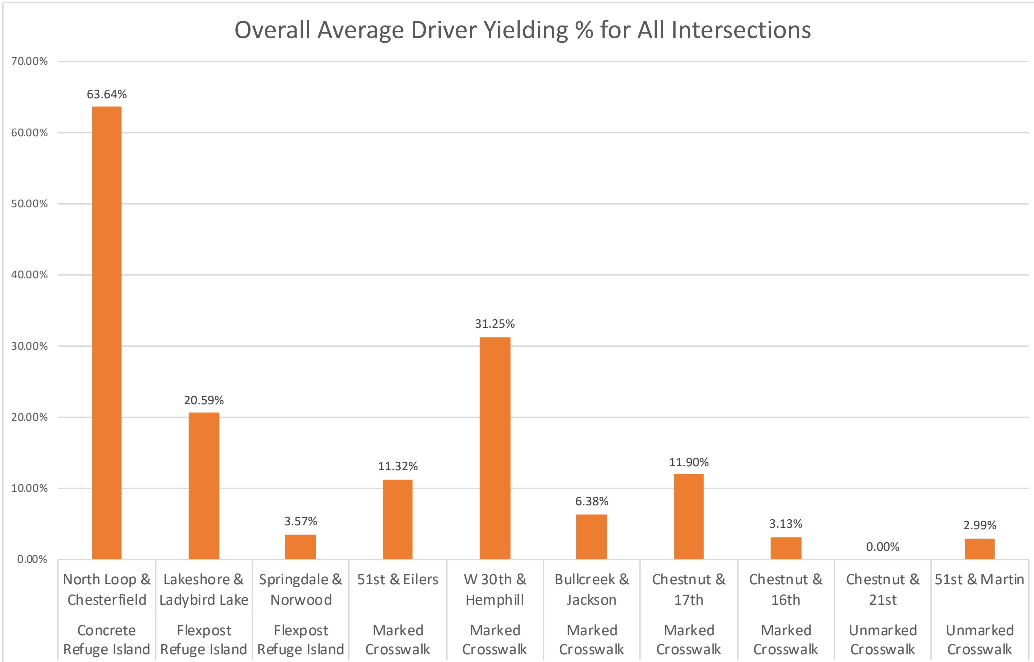

Figure 16 Average, Overall Yielding Rates for All Intersections

The highest overall yielding rate observed (63.64%) occurred at North Loop & Chesterfield, which has a concrete refuge island. On the other hand, the lowest rate observed was at Chestnut & 21st Street (0%), which has an unmarked crosswalk. Both of these locations have speed limits of 30 mph and are located within a residential area. The only difference noted between these two locations, besides crossing type, is the intersection geometry (Table 2). For the intersections included in this analysis, crossings of the same type have the same intersection geometry, with the exception of Bullcreek & Jackson. Therefore, this analysis cannot consider the effect of intersection geometry along with crossing type. Future work could locate intersections with varying geometries to test this effect.

Matching the results of the individual intersections, the concrete refuge island had the highest mean and unmarked crosswalks had the lowest mean. Crossings of the same type were aggregated to consider yielding rates by crossing type. Note, there was only one concrete refuge island. The combined results also show that marked crosswalks and flexpost islands have very similar yielding rates. It is not clear why these two very different treatments have very similar yielding rates, however, locations with flexpost islands do have higher speed limits than locations with marked crosswalks. Flexpost island locations have a speed limit of 40 mph, whereas marked crosswalk speed limits range between 25 and 30 mph. Therefore, these data suggest that at a 40 mph speed limit the conspicuousness of a flexpost island is similar to that of a marked crosswalk in a 30 mph (or less) environment.

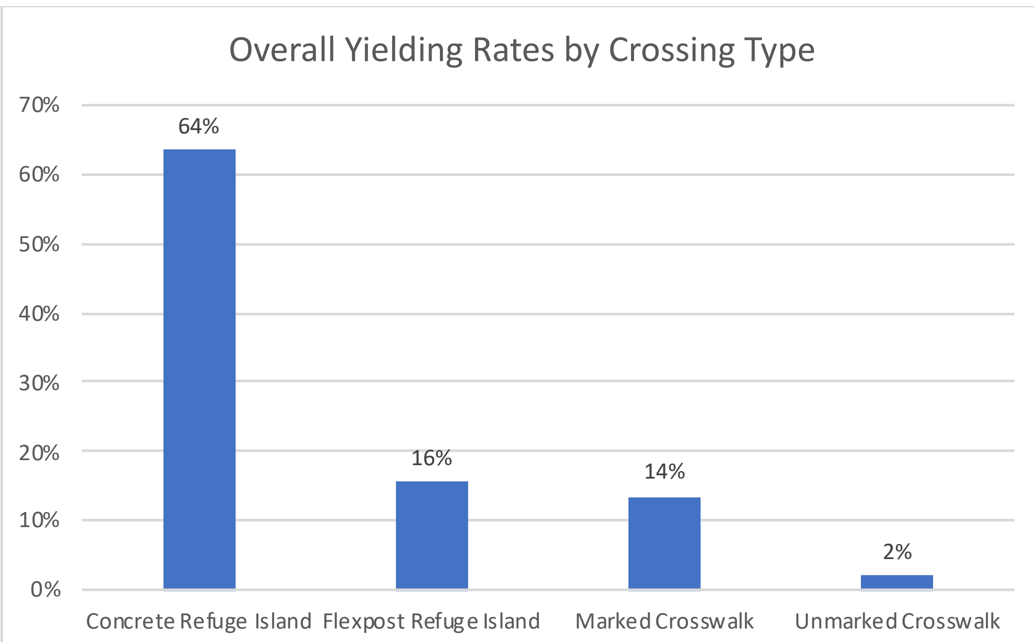

Figure 17 Yielding Rates by Crossing Type

To observe driver propensity to yield to pedestrians based on distance between the pedestrian and vehicles, near lane and far lane observations were counted and compared

Figure 18. These locations were all generally two-lane intersections, where the driver in the far lane was coming from the opposite direction.

Two out of four crossing types have superior near lane yielding rates. Far lane yielding rates were worse than near lane rates at the concrete refuge island and at marked crosswalks. At the concrete refuge island, perhaps drivers felt that the pedestrian could wait at the island before crossing to the second lane. The largest incongruency within a crossing type in far lane versus near lane rates occurred at marked crosswalks. Perhaps drivers in the far lane approaching marked crosswalks felt that they were far enough away to not need to slow down or stop for the pedestrian present on the other half of the roadway.

Flexpost islands and unmarked crosswalks showed slightly better far lane than near lane yielding rates. At unmarked crosswalks, drivers in the far lane yielded more than twice as often as drivers in the near lane. Unmarked crosswalks have an opposite relationship between near lane and far lane yielding rates, where the near lane rate is lower than the far lane rate. Although globally, yielding rates at marked crosswalks are very, very low.

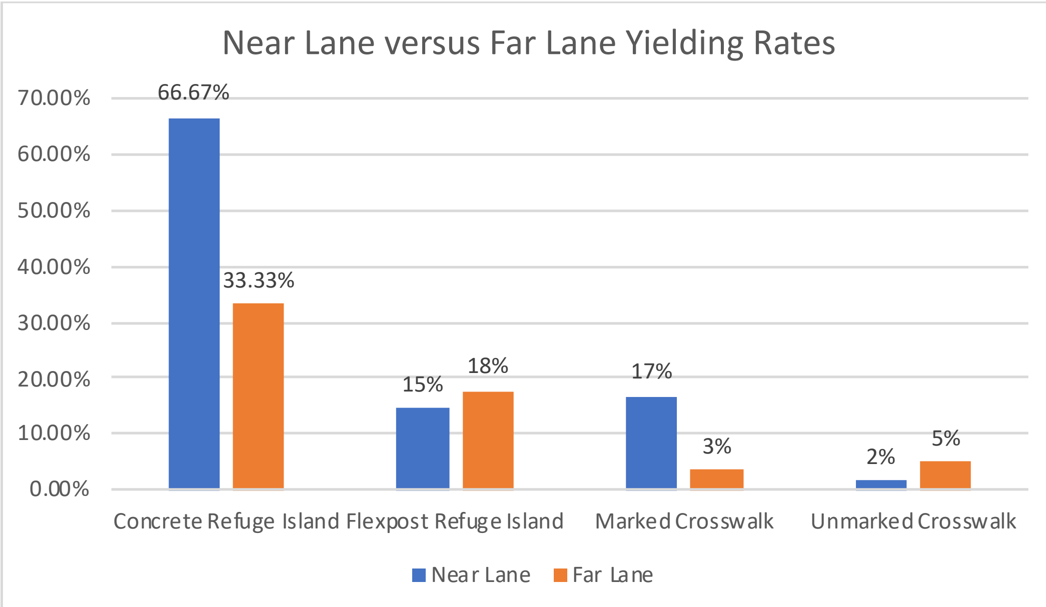

Figure 18 Near Lane versus Far Lane Yielding by Crossing Type

Lastly, while flexpost refuge islands and marked crosswalks have very similar overall yielding rates (Figure 17), the main difference between the two lies in the far lane yielding result. The high far lane yielding rate observed at flexpost islands is because of the Lakeshore & Ladybird Lake intersection, which is next to a park where drivers expect and respect high pedestrian activity to and from the park. The other flexpost island is located at Springdale & Norwood Hill and had nowhere near the overall yielding rates seen at Lakeshore & Ladybird Lake, as shown in Table 3. Therefore, the overall results from flexpost observations and marked crosswalks seem very similar. The following sections quantify these qualitative observations about crossing types using statistical techniques.

Effect of Crossing Types on Motorist Yielding Behavior

One-way analysis of variance (ANOVA) was conducted to determine whether there is any difference between the means of driver yielding rates in terms of crossing types. The null hypothesis is crossing type has no effect on driver yielding. For the crossing type model, the various factor levels are

1 = Concrete Refuge Island,

2 = Flexpost Refuge Island,

3 = Marked Crosswalk, and

4 = Unmarked Crosswalk.

The values used in the ANOVA come from the overall percentages shown in Table 3.

The overall F-test shows individual crossing treatments have an effect on yielding compliance Figure 19. The MSTR and the MSE are the first hint that the alternate hypothesis is true because they are nowhere near the same value (961.58 and 85.50, respectively). In testing the effect of crossing type on driver yielding behavior, the one-way ANOVA produces an F-Value = 11.25, which only has a 0.71% chance of occurring under a true null hypothesis. Given these numbers, the overall F-test checking whether each crossing types's effect equals zero, is rejected. Recall that factor effects are the differences between the mean of that factor level and the overall mean.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2884.73030	961.57677	11.25	0.0071
Error	6	512.97970	85.49662		
Corrected Total	9	3397.71000			

Root MSE	9.24644	R-Square	0.8490
Dependent Mean	15.47000	Adj R-Sq	0.7735
Coeff Var	59.77012		

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	23.23875	3.33652	6.96	0.0004
cross1	1	40.40125	7.34035	5.50	0.0015
cross2	1	-11.15875	5.70145	-1.96	0.0981
cross3	1	-8.04375	4.67113	-1.72	0.1358

Figure 19 Effect of Crossing Type ANOVA Result

The overall yielding mean in the factor effects models is given by,

$$\mu_{.} = 23.24.$$

The effect of each crossing type is given by the individual parameter estimates and are,

$$\tau_{concrete} = 40.40,$$

$$\tau_{flex} = -11.16,$$

$$\tau_{marked} = -8.04,$$

$$\tau_{unmarked} = -(40.40 - 11.16 - 8.04) = -21.20.$$

Out of the four types, a concrete refuge island offers the highest positive effect on yielding rates while an unmarked crosswalk results in the most negative effect on yielding rates. That is, the effect of a concrete island is +40.40 above the mean yielding rate. On the other hand, the effect of an unmarked crosswalk is -21.20 on motorist yielding rates. The final multiple regression equation with an R^2=0.8490 is

$$\hat{Y} = 23.24 + 40.40X_{ij1} - 11.16X_{ij2} - 8.04X_{ij3}$$

where,

$$X_{ij1} = \begin{Bmatrix} 1\ if\ case\ is\ crossing\ 1 \\ -1\ if\ case\ is\ crossing\ 4 \\ 0\ otherwise \end{Bmatrix},$$

$$X_{ij2} = \begin{Bmatrix} 1\ if\ case\ is\ crossing\ 2 \\ -1\ if\ case\ is\ crossing\ 4 \\ 0\ otherwise \end{Bmatrix},$$

and

$$X_{ij3} = \begin{Bmatrix} 1\ if\ case\ is\ crossing\ 3 \\ -1\ if\ case\ is\ crossing\ 4 \\ 0\ otherwise \end{Bmatrix}.$$

Since the null is rejected, conducting a more thorough analysis of the factor level means is warranted. The analysis of factor level means will calculate confidence intervals at a 95% level. As mentioned in the Methodology chapter, if zero appears in the confidence interval then we fail to reject the null hypothesis and the parameter is not contained within the interval at a 95% confidence level.

The 95% confidence interval (CI) and pairwise comparison results for each parameter estimate are shown in Figure 20. The 95% CI for the parameter estimates of each signage type are found in the top table under the columns labeled ‘Lower’ and ‘Upper’. The lower table shows the adjusted 95% CI for pairwise comparisons under the columns ‘Adj Lower’ and ‘Adj Upper’.

Least Squares Means									
Effect	cross	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
cross	1	63.6400	9.2415	6	6.89	0.0005	0.05	41.0269	86.2531
cross	2	12.0800	6.5347	6	1.85	0.1140	0.05	-3.9099	28.0699
cross	3	15.2125	4.6207	6	3.29	0.0166	0.05	3.9059	26.5191
cross	4	2.0400	5.3356	6	0.38	0.7154	0.05	-11.0157	15.0957

Differences of Least Squares Means														
Effect	cross	_cross	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
cross	1	2	51.5600	11.3185	6	4.56	0.0039	Tukey-Kramer	0.0152	0.05	23.8647	79.2553	12.3788	90.7412
cross	1	3	48.4275	10.3323	6	4.69	0.0034	Tukey-Kramer	0.0133	0.05	23.1453	73.7097	12.6601	84.1949
cross	1	4	61.6000	10.6712	6	5.77	0.0012	Tukey-Kramer	0.0048	0.05	35.4886	87.7114	24.6596	98.5404
cross	2	3	-3.1325	8.0034	6	-0.39	0.7090	Tukey-Kramer	0.9778	0.05	-22.7160	16.4510	-30.8378	24.5728
cross	2	4	10.0400	8.4363	6	1.19	0.2790	Tukey-Kramer	0.6540	0.05	-10.6029	30.6829	-19.1640	39.2440
cross	3	4	13.1725	7.0583	6	1.87	0.1113	Tukey-Kramer	0.3321	0.05	-4.0986	30.4436	-11.2613	37.6063

Figure 20 Least Squares Means Estimates and Pairwise Comparisons

The 95% CI for the true mean of yielding percentage at a concrete refuge island is (41.02, 82.25) and for a marked crosswalk is (3.91, 26.52). The 95% CI for flexpost islands and unmarked crosswalks were not significant.

For the pairwise comparisons, the difference between concrete refuge islands and every other treatment was significant. To maintain a family-wise error rate of 5%, the Tukey-Kramer adjustment was used. The difference between a concrete refuge island and flexplost island is estimated at 51.56, with a 95% CI equal to (12.38, 90.74). The interpretation is that there is a 95% chance that the difference between mean yielding rates at concrete refuge islands is between 12.38% and 90.74% more than the mean yielding rates at a flexpost island. The difference between concrete refuge islands and the other treatments can be found in an equivalent manner (see Figure 20). The results show that upgrading an unmarked crosswalk to a concrete refuge island can expect a mean yielding improvement of 61%. Future work can include more samples to determine statistically significant estimates for the parameters that did not reject the null hypothesis.

Effect of Signage Type on Motorist Yielding Behavior

The second one-way analysis reviewed the effect of signage type on motorist yielding behavior. For the signage type mode, the factor levels are,

1 = W11-2 Only,

2 = Family Only,

3 = Reg Combo, and

4 = Warn Combo.

For the model only considering signage as the factor in the model, the F-Value is 9.74 at a p-value 0.01 (Figure 21). At this value, we can reject the null and accept the alternative, which is that there is a difference in yielding rate by signage type.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2819.08423	939.69474	9.74	0.0101
Error	6	578.62577	96.43763		
Corrected Total	9	3397.71000			

Root MSE	9.82027	R-Square	0.8297
Dependent Mean	15.47000	Adj R-Sq	0.7446
Coeff Var	63.47942		

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	23.71063	3.88180	6.11	0.0009
sign1	1	-8.26313	5.20798	-1.59	0.1637
sign2	1	-12.46062	7.95532	-1.57	0.1683
sign3	1	39.92938	7.95532	5.02	0.0024

Figure 21 Effect of Signage Type ANOVA Result

The overall yielding mean in the factor effects models is given by,

$$\mu_{.} = 23.71.$$

The effect of each crossing type is given by the individual parameter estimates and are,

$$\tau_1 = -8.26,$$

$$\tau_2 = -12.46,$$

$$\tau_3 = 39.93,$$

and

$$\tau_4 = -(-8.26 - 12.46 + 39.93) = -19.21.$$

Out of the four types, the Reg Combo has highest positive effect on yielding rates with an improvement of +39.93 above the mean. The Reg Combo and Warn Combo have the biggest separation in terms of effects on driver yielding. Since the data collected for signage and crossings are not fully crossed, there is no way to determine whether interaction exists between these two factors.

The final multiple regression equation with an R^2=0.8297 is

$$\hat{Y} = 23.71 - 8.26X_{ij1} - 12.46X_{ij2} + 39.93X_{ij3}$$

where,

$$X_{ij1} = \begin{Bmatrix} 1\ if\ case\ is\ sign\ 1 \\ -1\ if\ case\ is\ sign\ 4 \\ 0\ otherwise \end{Bmatrix},$$

$$X_{ij2} = \begin{Bmatrix} 1\ if\ case\ is\ sign\ 2 \\ -1\ if\ case\ is\ sign\ 4 \\ 0\ otherwise \end{Bmatrix},$$

and

$$X_{ij3} = \begin{Bmatrix} 1\ if\ case\ is\ sign\ 3 \\ -1\ if\ case\ is\ sign\ 4 \\ 0\ otherwise \end{Bmatrix}.$$

Since the null is rejected, the 95% confidence interval (CI) and pairwise comparison tests were calculated. The results for each parameter estimate are shown in Figure 22.

Least Squares Means									
Effect	sign	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
sign	1	15.4475	4.9101	6	3.15	0.0199	0.05	3.4328	27.4622
sign	2	11.3200	9.8203	6	1.15	0.2929	0.05	-12.7093	35.3493
sign	3	63.6400	9.8203	6	6.48	0.0006	0.05	39.6107	87.6693
sign	4	4.5050	4.9101	6	0.92	0.3943	0.05	-7.5097	16.5197

Differences of Least Squares Means														
Effect	sign	_sign	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
sign	1	2	4.1275	10.9794	6	0.38	0.7199	Tukey-Kramer	0.9802	0.05	-22.7381	30.9931	-33.8799	42.1349
sign	1	3	-48.1925	10.9794	6	-4.39	0.0046	Tukey-Kramer	0.0180	0.05	-75.0581	-21.3269	-86.1999	-10.1851
sign	1	4	10.9425	6.9440	6	1.58	0.1661	Tukey-Kramer	0.4554	0.05	-6.0488	27.9338	-13.0955	34.9805
sign	2	3	-52.3200	13.8880	6	-3.77	0.0093	Tukey-Kramer	0.0353	0.05	-86.3026	-18.3374	-100.40	-4.2440
sign	2	4	6.8150	10.9794	6	0.62	0.5576	Tukey-Kramer	0.9218	0.05	-20.0506	33.6806	-31.1924	44.8224
sign	3	4	59.1350	10.9794	6	5.39	0.0017	Tukey-Kramer	0.0068	0.05	32.2694	86.0006	21.1276	97.1424

Figure 22 Least Squares Means Estimates and Pairwise Comparisons for Sign Type

As before, the top table in Figure 22 shows the 95% CI parameter estimates for each signage type under the columns labeled 'Lower' and 'Upper'. The 95% CI that are statistically significant are the W11-2 and the Reg Combo estimates at (3.43, 27.46) and (29.61, 87.67), respectively. The bottom table shows the pairwise comparisons for all six combinations.

The estimate for the difference between W11-2 Only & Reg Combo, Family Only & Reg Combo, and Reg Combo & Warn Combo are significant. The largest difference is observed between the Reg Combo and Warn Combo configuration. The Reg Combo shows an improvement of 59.14 over the Warn Combo with a 95% CI of (21.12, 97.14). This result seems a little strange because the only difference between a Warn Combo and a Reg Combo is the presence of an advanced warning sign ahead of the sidewalk. Additionally, one would think that adding an additional sign would improve yielding/awareness, but the results seem to suggest the opposite. Since interaction with other factors, such as crossing type, have not been taken into account, this result should be taken with a grain of salt.

Effect of Platooning and Crossing Type on Motorist Yielding Behavior

The effect of platooning and crossing types on driver yielding behavior was also evaluated with a Two-Way ANOVA. It was suspected that perhaps one group would have a higher yielding rate over the other during the data reduction process and that considering platooning could explain additional variability in the model. For each crossing type, the number of drivers belonging and not belonging to a platoon were tallied. Table 4 shows the data used for this analysis. Each column shows the total number of observations used to calculate the percentage of each factor level (vehicles belonging or not belonging to a platoon) and the overall yielding rate for each.

Crossing types 2, 3, and 4 were eligible for the two-way analysis given the number of observations. For this part, the observations for flexplost island, marked crosswalks, and unmarked crosswalks were aggregated to meet the standard minimum sample size of 30 requirement. For these crossing types the minimum number of observations in the platoon and non-platoon category were met after aggregating the results from the individual intersections show in Table 3.

Table 4 Platooning and Crossing Two-Way ANOVA Data

	Platoon		Non-Platoon		Overall	
Crossing	**# of Obs**	**Yield %**	**# of Obs**	**Yield %**	**# of Obs**	**Yield %**
Flexpost Refuge Island (2)	38	21.05%	58	12.07%	96	15.63%
Marked Crosswalk (3)	39	17.95%	198	12.63%	237	13.50%
Unmarked Crosswalk (4)	32	6.25%	107	0.93%	141	2.13%

As mentioned in the Methodology chapter, since there is only one sample for each combination of factors, we have to assume there is no interaction between crossing type and platoon. That means the model cannot recognize if the yielding response at certain crossing types does not depend on whether the observation is from a platoon or not. For this case the assumption of no interaction seems reasonable.

Figure 23 shows the interaction plot for this dataset. The horizontal axis shows the three crossing types meanwhile the vertical axis shows yielding rates. The blue line represents the yielding rates for vehicles belonging to platoons while the red line represents rates for vehicles that did not belong to platoons. There is a slight difference in slopes between the two lines at crossing 2 and crossing 3. In the future, further data collection and a two-way analysis of variance could confirm if there is significant interaction occurring. But, since the distance between these two lines generally seems equal, then assuming no interaction is acceptable (Figure 23).

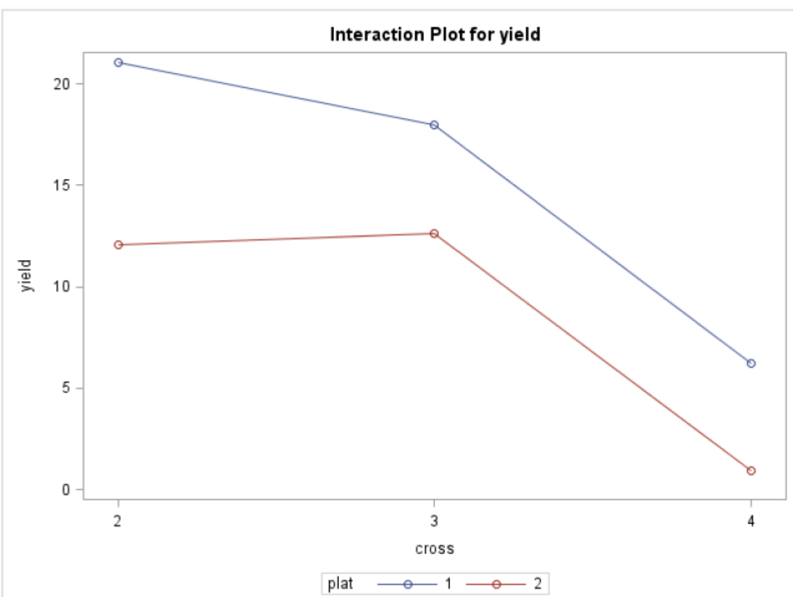

Figure 23 Interaction Plot for Two-Way ANOVA

The Two-Way analysis generated an F-value of 40.11, which is significant with a p-value of 0.02. Therefore, the F-test is rejected and there is a difference between the means of the crossing treatments and the means of vehicles belonging to platoons. Looking at the variability as described by the 'Sum of Squares' column, clearly most of the variability is being explained by including both of these factors in the model. The total variance is 273.11, the explained variance is 268.64, and the unexplained (error) variance is only 4.47. The R^2 in this case is 0.94.

The lower table showed in Figure 24 takes a closer look at each of the main effects. Again, since this model only has a sample size of n=1 for each combination of factors, the error term used in calculating the F statistic was the MSAB (mean squares of the interaction between Crossing and Platooning). Both main effects for crossing type and platooning produced p-values that are significant enough (0.02, 0.03, respectively). Looking at the Type 3 Sums of Squares shows that crossing type explains more variability than the platooning factor.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	268.6399333	89.5466444	40.11	0.0244
Error	2	4.4652000	2.2326000		
Corrected Total	5	273.1051333			

R-Square	Coeff Var	Root MSE	yield Mean
0.983650	12.64832	1.494189	11.81333

Tests of Hypotheses Using the Type III MS for cross*plat as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
cross	2	204.4825333	102.2412667	45.79	0.0214
plat	1	64.1574000	64.1574000	28.74	0.0331

Figure 24 Crossing Type and Platooning Two-Way ANOVA Result

The results reported here contradict the some of the findings in the literature with respect to platoons. Some studies have reported that platooning cars tend to yield less to pedestrians, perhaps because of lack of visibility. However, the results from this case show yielding rates for vehicles in platoons are slightly higher than for vehicles not belonging to platoons. The site characteristics likely influenced the results. The sites used in this analysis were local low-volume streets, with only two lanes to cross, and sometimes a bike line. In general, the nearby land-uses were residential. During times when a low-volume street experienced more traffic (higher likelihood of platoons forming), vehicles belonging to a platoon worried about other vehicles not yielding and were more predisposed to allow the pedestrian to cross the street.

EFFECT OF CROSSING TREATMENTS ON PEDESTRIAN CRASH RATES

The second part of this chapter describes the results from Austin, Texas exploratory pedestrian fatality crash analysis. Legal pedestrian crash scenarios were reviewed to determine if they occurred within a reasonable distance (358 ft) of a pedestrian crossing facility. Furthermore, crashes that occurred with a treatment present were categorized as ‘marked’ or ‘unmarked’ treatments.

The total number of all reported pedestrian crashes in Austin, Texas from 2015, 2016, and 2016 is 409, 427, and 391, respectively. The breakdown of pedestrian crashes by crash type is given in Figure 25.

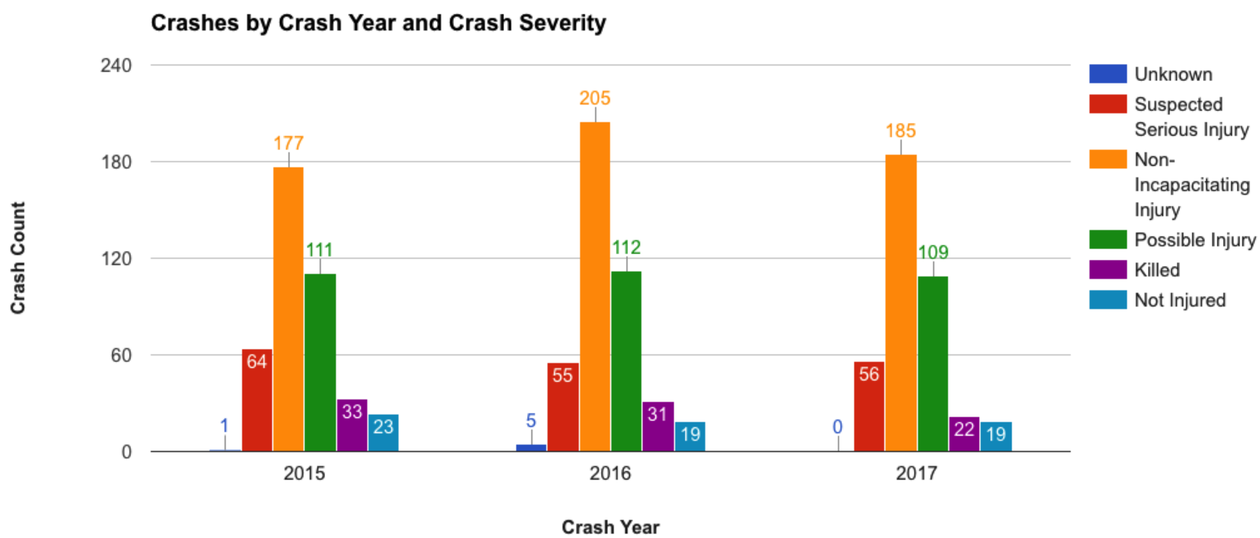

Figure 25 Crashes by Year and Severity for Austin, Texas

In Austin, Texas, pedestrian fatalities slightly decreased between 2015 and 2017. In 2015, pedestrian fatalities made up about 8% of all crashes. The following year, pedestrian fatalities made up 7% of all crashes. Finally, in 2017, 6% of pedestrian-related crashes were fatal.

From the FARS database, a total of 86 pedestrian fatality crashes were extracted for the 3-year analysis period. The number of pedestrian fatalities for these three years match between the FARS and CRIS databases. Figure 26 shows the individual fatal crash data points. Since some of the points overlap, Figure 27 summarizes the entire dataset for this study by way of a heat map. The brighter, more yellow-colored locations indicate higher crash frequency. These crashes generally occurred under daylight and clear weather conditions. The primary manner of collision was ‘one motor vehicle going straight’. See appendix for further details.

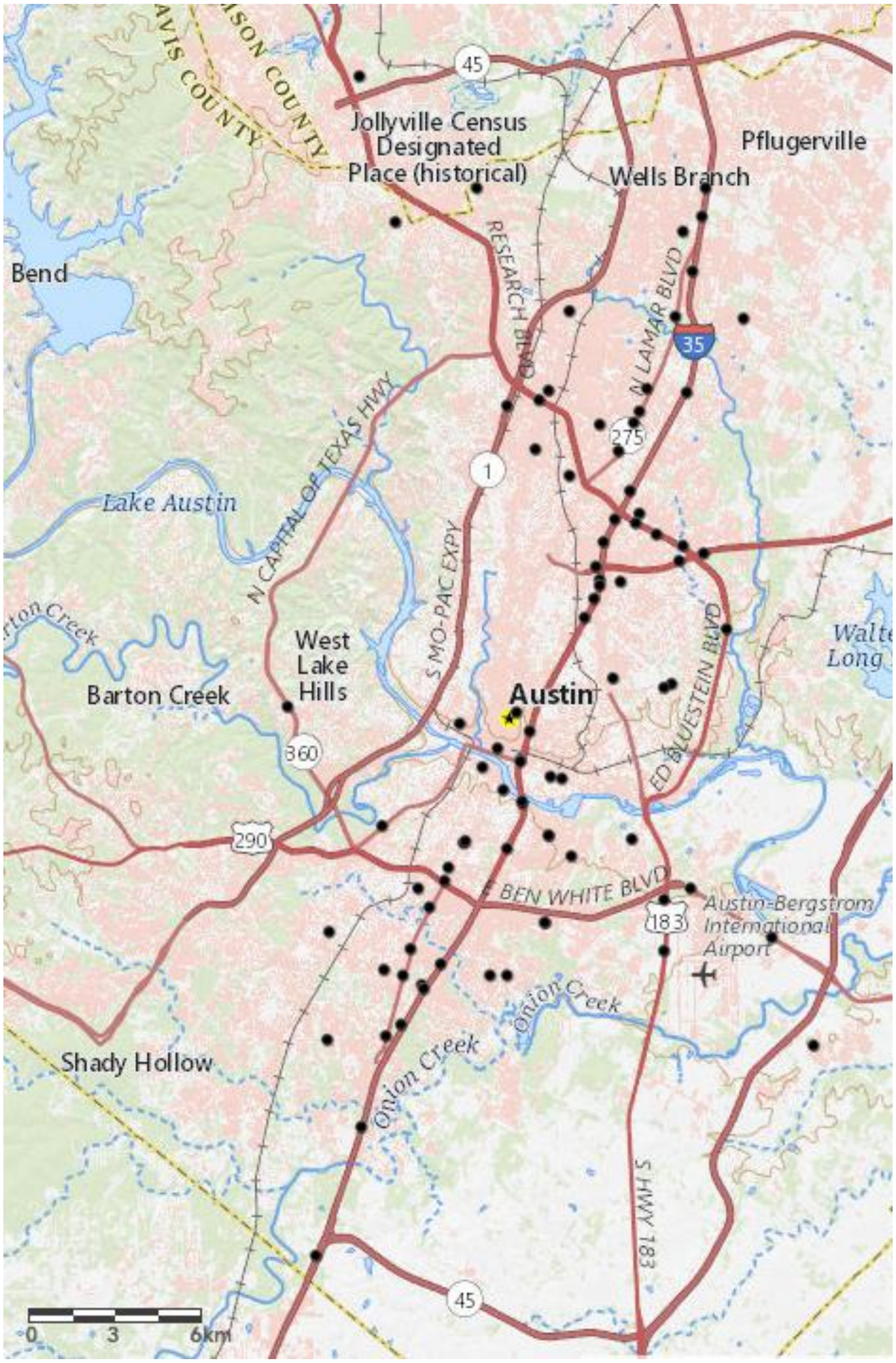

Figure 26 Map Pedestrian Fatalities 2015-2017 in Austin, Texas

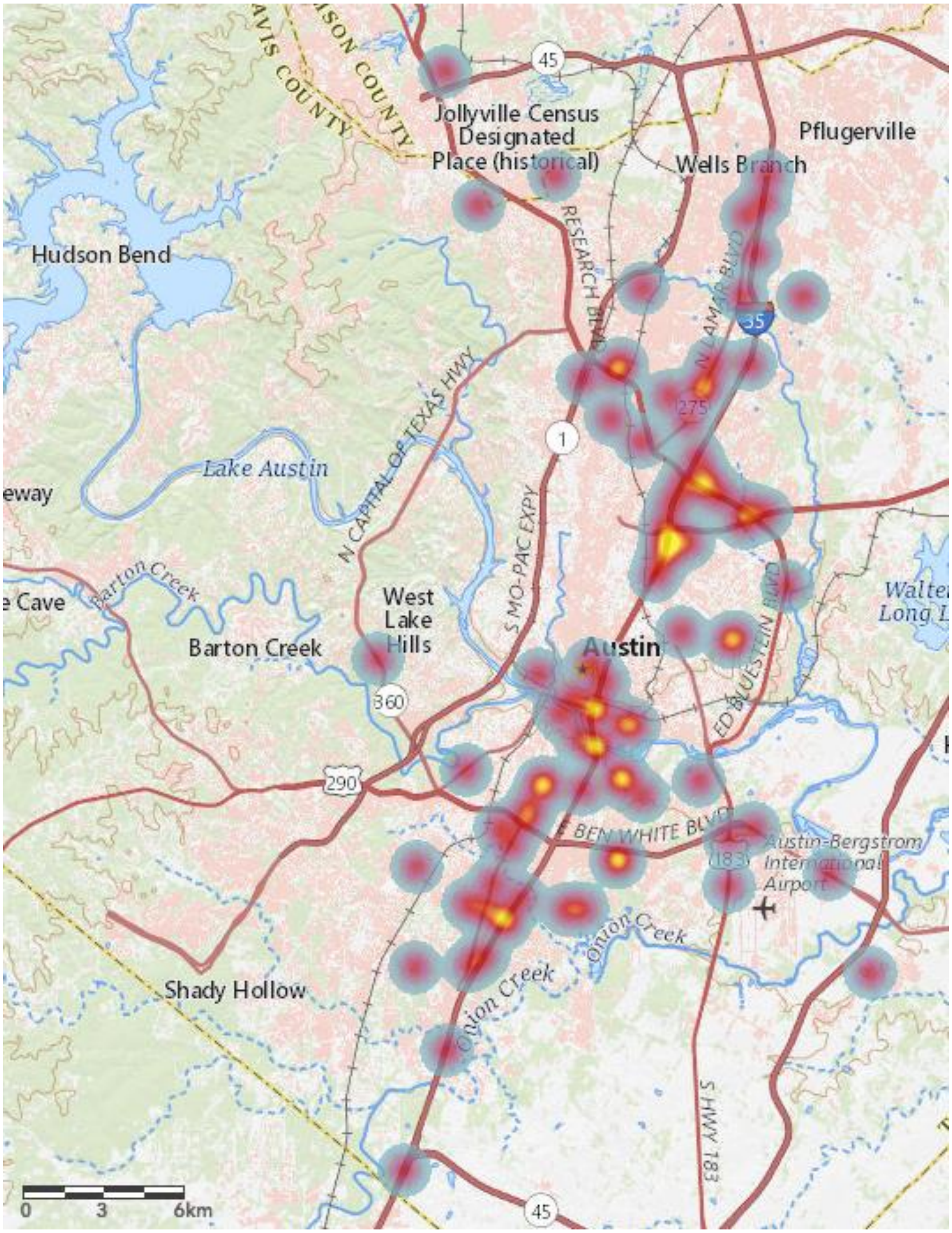

Figure 27 Heat Map of Austin Pedestrian Fatalities in Austin, Texas

Presence of Crossing Treatment and Pedestrian Crash Rates

Two-way ANOVA was used on both the entire dataset and on only the legal crossing scenarios to pinpoint differences between the two types of crash scenarios. Education and enforcement can more appropriately target crashes occurring under illegal crossing. On the other hand, information from crashes related to legal crossing scenarios are more appropriate for guiding improvements to the built environment. For all of these cases, the sample size, n =1. Therefore, the interaction term was used as an estimate of the variance.

The first ANOVA considered sidewalk presence and marked versus unmarked crossings (Table 5) using the entire crash dataset. There is a higher share of pedestrian fatal crashes occurring when there is no sidewalk and the pedestrian crossing treatment is present. The lowest number of fatal pedestrian crashes occurs when there is a sidewalk present and the pedestrian crossing treatment is present.

Table 5 Two-way ANOVA (sidewalk presence - full dataset)

All Data	**sidewalk (1)**	**no sidewalk (2)**
present (1)	26.74%	32.56%
not present (2)	2.33%	31.40%

The interaction plot shown in Figure 28 clearly shows the two lines (level of factor treatment presence) approaching each other when there is no sidewalk present. The blue line indicates pedestrian treatment presence or no pedestrian treatment while the horizontal axis shows whether a sidewalk is present.

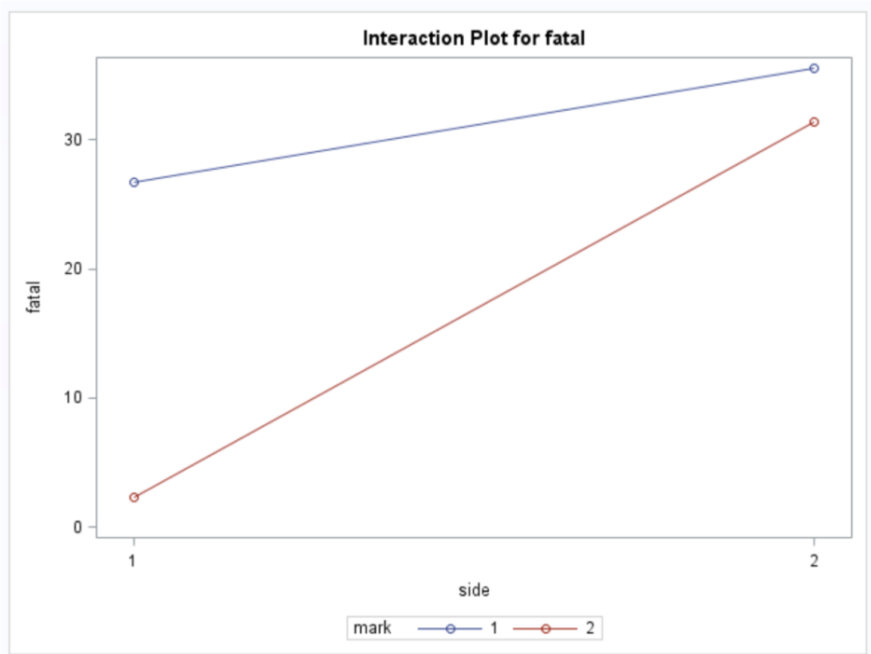

Figure 28 Interaction Plot for Two-way ANOVA (sidewalk presence - full dataset)

These interaction plots indicate a violation of the two-way ANOVA with n=1, which assumes there is no interaction between Factor A, sidewalk presence, and Factor B, pedestrian treatment presence. The effect of a pedestrian treatment is much larger when there is no sidewalk present.

Table 6 shows that the difference in percentage of fatality crashes is not significant at any of these factor levels for sidewalk presence and treatment presence. Both of the main effects tested did not produce an F value large enough to reject the null hypothesis at a confidence level of 0.05. The next ANOVA shows the results from using these two factors on the data from legal crossing scenarios only.

Table 6 F-Test Result (sidewalk presence - full dataset)

Tests of Hypotheses Using the Type III MS for side*mark as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
side	1	358.9130250	358.9130250	3.50	0.3125
mark	1	204.0612250	204.0612250	1.99	0.3925

The results from the ANOVA considering both pedestrian crossing treatment and sidewalk presence on only the crashes which occurred under legal crossing scenarios is shown in Table 7. Both the table and Figure 29 show that the effect of treatment presence is very similar whether or not a sidewalk is present. Here, the difference between fatality crashes at locations with and without pedestrian crossing treatments is less when there is no sidewalk present.

The result from considering legal crossing scenarios only makes perfect sense given the metrics used. These crash data were not combined with exposure data, which are necessary for contextualizing the statistics. Locations with sidewalks and pedestrian treatments should attract more pedestrians, therefore increasing the likelihood of a pedestrian crash. Therefore, a future next step could consider a surrogate measure for pedestrian volumes, such as ridership for the nearest transit station, to try to estimate exposure.

Table 7 Two-way ANOVA (sidewalk presence - legal only)

Legal Only	**sidewalk**	**no sidewalk**
present	5.81%	2.33%
not present	0.00%	0.00%

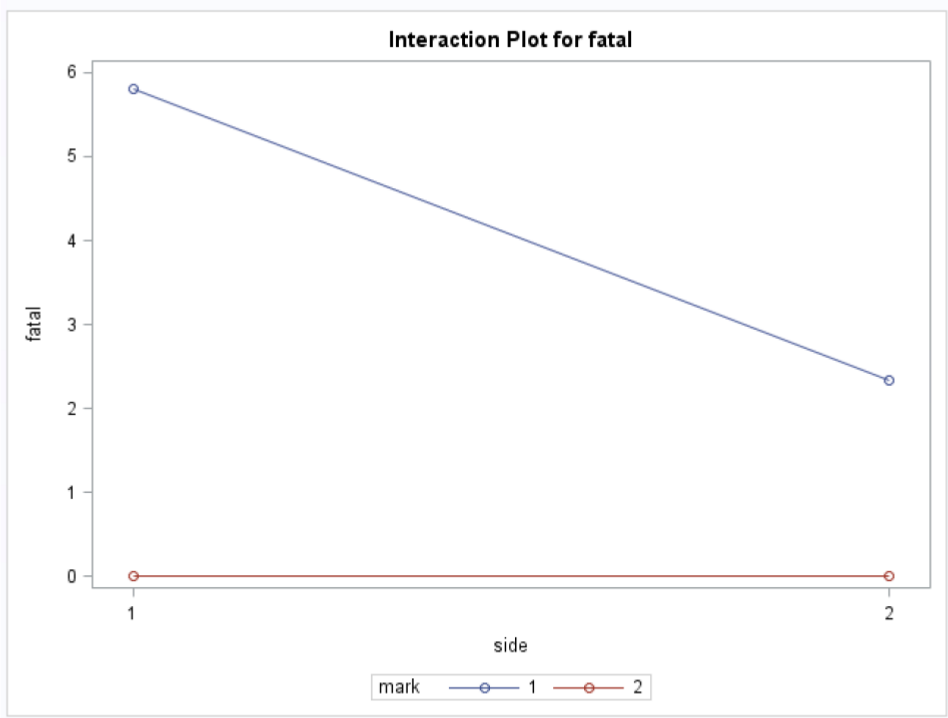

Figure 29 Interaction Plot for Two-way ANOVA (sidewalk presence - legal only)

The F test assessing whether there is a difference in means between crossing presence and treatment presence shows that the null hypothesis cannot be rejected with this particular data. Therefore, this test does not show statistically significant differences in the means of sidewalk presence and pedestrian treatment presence.

Table 8 F-Test Result (sidewalk presence - legal only)

Tests of Hypotheses Using the Type III MS for side*mark as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
side	1	3.02760000	3.02760000	1.00	0.5000
mark	1	16.56490000	16.56490000	5.47	0.2572

The last two ANOVAs considered nearby bus stops as another factor explaining the share of pedestrian fatalities. The same distance that was used for determining whether a crossing treatment was present within a reasonable distance of 358 ft was used. This distance is roughly equivalent to a 1 ½ minute walk.

Using the entire dataset, percentages of fatal crashes were calculated in terms of pedestrian crossing treatment presence and bus stop proximity. The results are shown in Table 9. More pedestrian crashes occur at locations that have bus stops more than 358 ft away and a crossing treatment present. This result is slightly surprising because one would expect that bus stops might attract more pedestrians, therefore increasing the number of pedestrian crashes.

Table 9 Two-way ANOVA (bus stop presence - full dataset)

All Data	**bus stop < 358 (1)**	**bus stop > 358 (2)**
present (1)	2.33%	34.88%
not present (2)	0.00%	27.91%

The result from the overall f-test hint that there is a difference in the share of pedestrian fatalities occurring at the different levels of these two factors (treatment presence, bus stop presence). The p-value for the overall F-test is 0.07, which is technically not rejected at the standard 0.05 level, however, this value is very close to significance. The Sum of Squares (SS) results show that most of the variability is being explained by the model (935.5 out of 940.9). Moreover, most of the variability is being explained by bus stop presence as shown in the Type III SS result. The results of the main effects f-test show that bus stop presence is significant at a p-value of 0.049. Therefore, we reject the null hypothesis for this effect and there is a difference in proportion of pedestrian fatalities when considering bus stop presence or proximity.

Table 10 F-Test Results (bus stop presence - full dataset)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	935.4754000	467.7377000	86.90	0.0756
Error	1	5.3824000	5.3824000		
Corrected Total	3	940.8578000			

Tests of Hypotheses Using the Type III MS for bus*mark as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
bus	1	913.8529000	913.8529000	169.79	0.0488
mark	1	21.6225000	21.6225000	4.02	0.2946

The interaction plot for bus stop presence using the full data set shows very little difference in slope between the blue line (pedestrian treatment present) and red line (no pedestrian treatment present). The lack of difference in slopes hints that there is very little to no interaction between treatment and bus stop presence. Therefore, the assumption of no interaction needed for using a two-way ANOVA with n=1 is satisfied.

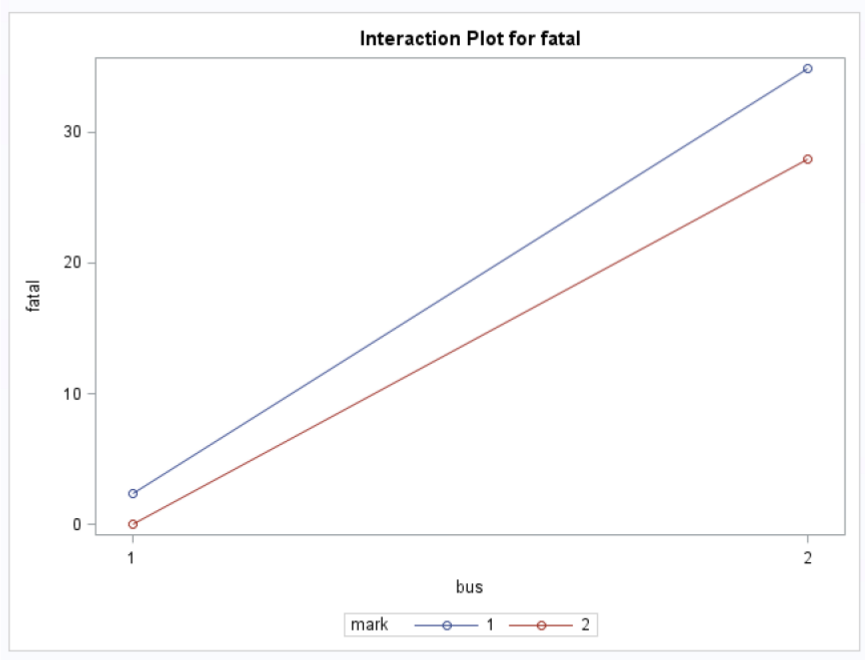

Figure 30 Interaction Plot for Two-way ANOVA (bus stop presence - full dataset)

The last ANOVA considered once again bus stop presence and pedestrian treatment presence, but only for crashes that occurred under legal crossing circumstances. Opposite from the previous result, most crashes under legal crossing circumstances occurred at bus stops within 358 ft and with a treatment present. Zero crashes occurred in Austin, Texas under legal crossing locations, with no pedestrian treatment, and a bus stop within very close proximity.

Table 11 Two-way ANOVA (bus stop presence - legal only)

Legal Only	**bus stop < 358 (1)**	**bus stop > 358 (2)**
present (1)	20.93%	11.63%
not present (2)	0.00%	2.33%

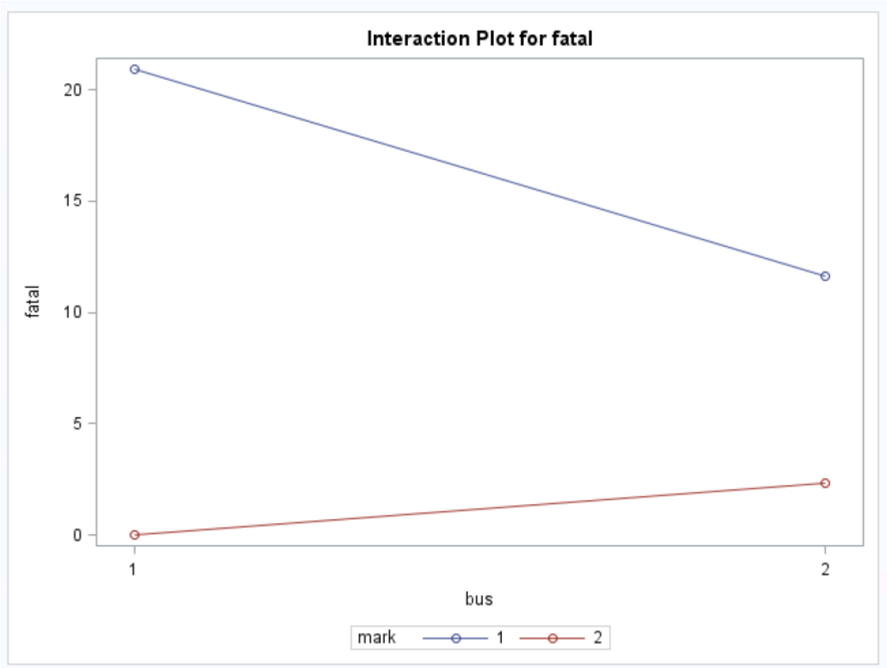

Figure 31 Interaction Plot Two-way ANOVA (bus stop presence - legal only)

The interaction plot in Figure 31 shows a negative slope in the blue line (treatment present) and a positive slope for the red line (no treatment present). Therefore, interaction seems to exist between bus stop proximity and presence of pedestrian treatment. The difference between treatment presence on pedestrian fatality percentage is less when there is a bus stop more than 358 ft away. In this case, the F test cannot be rejected at a 0.05 level. For this scenario, more variability in pedestrian fatality percentage is explained by the presence of a pedestrian crossing treatment (Type III SS = 228.5) rather than by presence of a bus stop (Type III SS = 12.15).

Table 12 F-Test Result (bus stop presence - legal only)

Tests of Hypotheses Using the Type III MS for bus*mark as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
bus	1	12.1452250	12.1452250	0.36	0.6563
mark	1	228.4632250	228.4632250	6.76	0.2338

These results are a starting point for understanding the effect of pedestrian control devices on fatal pedestrian crashes. These two-way ANOVAs were created with a low number of observations and small number of factor levels (only two in each). The interaction plots provide a first-look at the potential interaction between pedestrian treatment presence, and bus stop proximity or sidewalk presence.

SUMMARY

This chapter illustrated the results from the pedestrian yield experimentation and the exploratory fatal crash data analysis. The results were interpreted in terms of the effects pedestrian control devices have on both yielding behavior and the percentage of fatal crashes. The following chapter summarizes the conclusions and recommendations gathered from these pieces of work.

Conclusions

Understanding how different types of crossing treatments affect 1) driver propensity to yield to pedestrians and 2) fatal crash rates can allow practicing professionals to better address pedestrian safety concerns. Examining both motorist yielding behavior and fatal crash data delivers a comprehensive look at pedestrian safety.

EFFECT OF PEDESTRIAN CONTROL DEVICES ON YIELDING BEHAVIOR

The investigation evaluated driver yielding behavior rates with respect to crossing type and signage type, separately. Additionally, the effect of traveling in a platoon was also tested in conjunction with the effect of control devices to see if it explained additional variability. A list summarizing the key findings follows.

- *Concrete islands result in the highest yielding rates out of the tested crossing types.* Concrete refuge islands had the highest mean and unmarked crosswalks had the lowest mean. Marked crosswalks and flexpost islands have very similar average yielding rates.
- *The effect of a flexpost island is not significantly different from the effect of a marked crosswalk on driver yielding propensity.* The effect of a concrete refuge island is +40.40%, the effect of a flexpost island is -11.16%, marked crosswalk is -8.04%, and unmarked crosswalk is -21.21%.
- *At a 95% confidence level, concrete refuge islands can result in up to 82% yielding compliance while marked crosswalks can result in an upper yielding compliance of 27%.* The 95% CI for the true mean of yielding percentage at a concrete refuge island is (41.02, 82.25) and for a marked crosswalk is (3.91, 26.52).

- *For the pairwise comparisons, the difference between concrete refuge islands and every other treatment was significant at a family-wise error level of 5%.* Upgrading an unmarked crosswalk to a concrete refuge island can result in +61% yielding compliance improvement. Equivalent conclusions for the rest of the pairwise comparisons can be drawn from Figure 20.
- *There is a difference in yielding rate by signage type, however, future work should consider crossing types as a second factor.* Certain signage configurations only occurred at specific crosswalk types, meaning signage types are nested within the crossing type. With this dataset, it was not possible to construct a fully crossed two-way ANOVA.
- *Little to no interaction exists between crossing type and platooning.* This means that the effect of platooning does not depend on the crossing type. The crossing types that were tested were flexpost islands, marked crosswalks, and unmarked crosswalks. No matter the crossing type, the effect of platooning was the same.
- *Vehicles belonging to platoons tend to have a higher propensity to yield to pedestrians.* There is a difference between the means of the crossing treatments and the means of vehicles belonging to platoons. The platooning effect was tested for flexpost islands, marked crosswalks, and unmarked crosswalks.

EFFECT OF PEDESTRIAN CONTROL DEVICES ON FATAL CRASH RATES

An exploratory analysis of pedestrian crash fatality percentages was conducted considering presence of a crossing treatment along with two other explanatory factors:

sidewalk and bus stop presence. Both the entire dataset and a subset of data only considering potentially legal crossing circumstances was used to conduct tests. The statistical tool used for the analysis assumes there is no interaction between the two explanatory factors. The following is a summary of the findings:

With respect to all fatal crashes occurring in Austin, Texas during the analysis period:

- The effect of a pedestrian treatment is larger on pedestrian fatalities when there is no sidewalk present. Interaction seems to exist between treatment and sidewalk presence.
- There is a significant difference in proportion of pedestrian fatalities when considering bus stop presence or proximity. No interaction seems to exist between treatment presence and bus stop presence. The majority of variability is explained by the bus stop main effect.

With respect to only the fatal crashes at locations that provide a legal crossing opportunity:

- The difference in fatality crashes at locations with and without pedestrian crossing treatments is less when there is no sidewalk present. Interaction seems to exist between treatment and sidewalk presence.
- The difference between treatment presence on pedestrian fatality percentage is less when there is a bus stop more than 358 ft away. Interaction seems to exist between treatment and sidewalk presence. The majority of the variability is explained by the treatment main effect.

RECOMMENDATIONS FOR IMPLENTATION

In light of these conclusions, the following list provides recommendations for practicing professional working on pedestrian safety issues:

- The effect of a flexpost island is very similar to the effect of a marked crosswalk. Flexpost islands are harder to maintain and are more predisposed to damage from objects that strike them. Based on the literature review, an R-16 sign gateway configuration could offer much more in terms of yielding improvements at a very reasonable cost.
- The effect of platoons does not seem to interact with pedestrian crossing treatments in terms of driver yielding propensity, therefore improvement efforts should not worry too much about the difference in benefits of pedestrian treatments at locations where platooning is more likely.
- Consider improvements to pedestrian fatality hot spot locations in light of sidewalk presence and bus stop proximity. The effect of a treatment is not uniform across all level of both of these factors.
- Place signs to encourage bus riders to cross at the nearest intersection, even though it may seem inconvenient.

Appendix

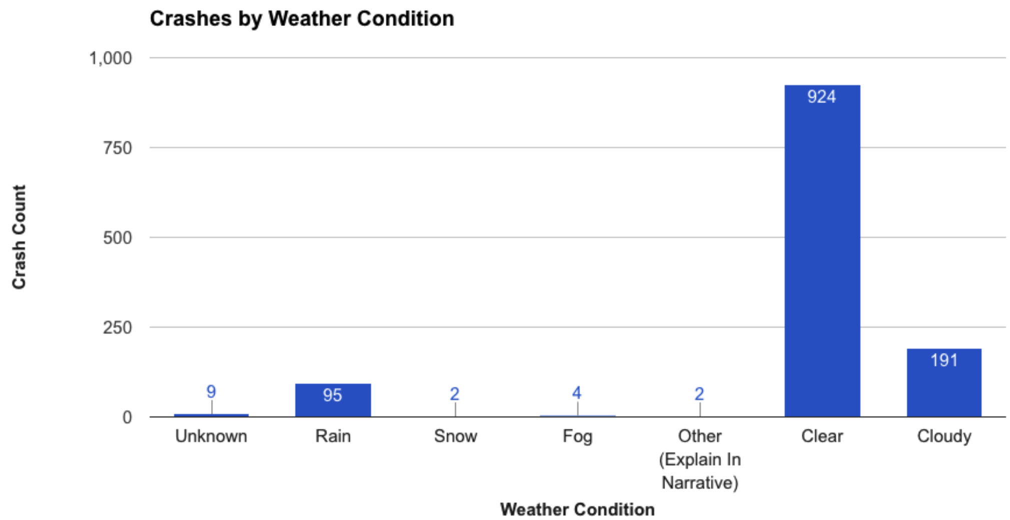

Figure 32 Pedestrian Fatal Crashes by Weather Condition in Austin, Texas

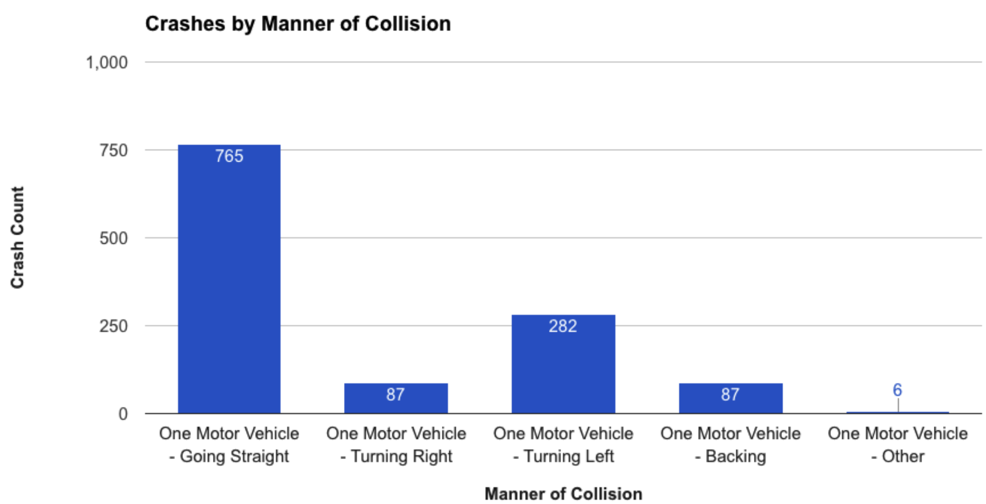

Figure 33 Pedestrian Fatal Crashes by Manner of Collision in Austin, Texas

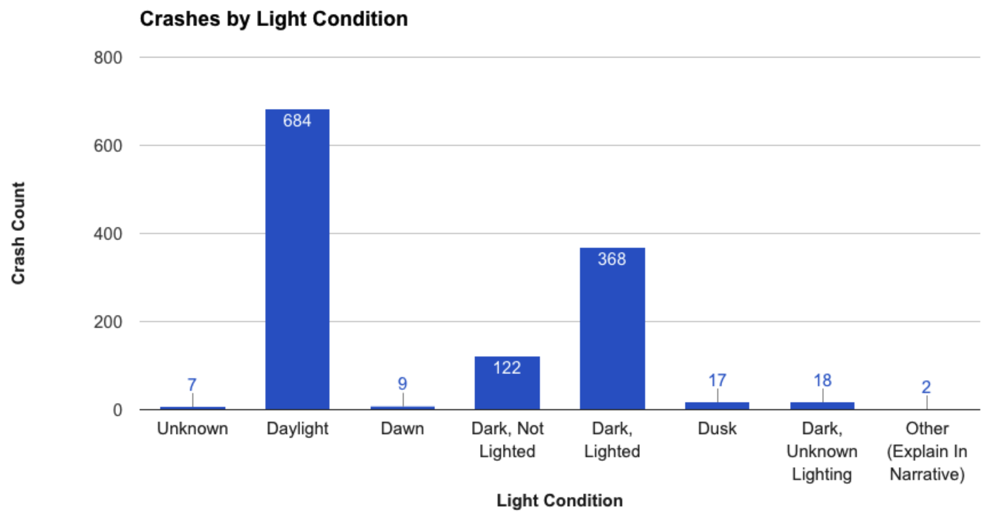

Figure 34 Pedestrian Fatal Crashes by Light Condition in Austin, Texas

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